PROCEEDINGS

EAAE-ARCC CONFERENCE 2024

ARCHITECTURE INTO THE UNKNOWN

23-26 MAY

AARHUS SCHOOL OF ARCHITECTURE

European Association for Architectural Education
Association Européenne pour l'Enseignement de l'Architecture

ARCC
architectural research centers consortium

AARHUS SCHOOL OF ARCHITECTURE

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http://www.arcc-arch.org

ARCC
architectural research centers consortium

Founded in 1976, the ARCC is an international association of architectural research centers, academies and organizations committed to the research culture and supporting infrastructure of architecture and related design disciplines. Through conference programming, grant and award programs, workshops and research journal Enquiry, ARCC represents a concerted commitment to improve the quality of life in the built environment.

Historically, ARCC's members have been schools of architecture who have made substantial commitments to architectural research, often by forming centers directed to research programs. At the same time, ARCC has sponsored many projects, conferences, and other activities involving the broader architectural research community, including industrial laboratories, government agencies, non-profit organizations, and private practitioners engaged in research.

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As an organization of researchers and research centers, ARCC sponsors workshops, undertakes sponsored projects, sustains networks, and exchanges information and experience intended to help build a research culture and infrastructure — in architecture schools and beyond.

EAAE
https://www.eaae.be/

European Association for Architectural Education
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The European Association for Architectural Education is an international, membership-based Association organizing architectural schools in Europe. Membership is not limited to countries that belong to the European Union, all European countries may participate. The EAAE is a non-profit, Belgian registered organization.

The purpose of the Association is to advance the quality of architectural education and also to promote the quality of architecture in Europe. The Association provides a forum for generating information on aspects of architectural education and architectural research.

The mission of the Association is to build a network of European schools of architecture, fostering discussions, exchanges and a common policy in Europe to advance the quality of architectural education. The EAAE promotes the interests of member schools as institutions and academic environments.

Aarhus School of Architecture
https://aarch.dk/

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EAAE PRESIDENT'S PREFACE

OYA ATALAY FRANCK, EAAE PRESIDENT 2017-2024

Uncertainty and change have always been part of our lives. In recent years, however, we have witnessed a series of disruptive developments and events—some long in the making—that have left us both stunned and disoriented.

Climate change has been on the agenda of scientists, governments, and the media worldwide for decades. Yet the persistent inability—and perhaps lack of political will—to honor the 2016 Paris Agreement and limit global warming to 1.5 degrees Celsius (a threshold already surpassed) places us at, or even beyond, the point of no return. The Covid-19 pandemic, the ongoing war in Ukraine, the humanitarian crisis in the Middle East, the alarming loss of biodiversity, the deepening inequalities, and global migration—the list of challenges is daunting, and the problems are vast and complex. What can architecture contribute in these times? What is the role of the architect and of architectural education when technological advances—especially in AI—are challenging the very core of our societies and our roles as individuals? Is, to paraphrase Marshall Berman's 1982 book title, "everything that is solid melting into air"?

We have left the certainties of modernity far behind and now live in the era of the Anthropocene—a term proposed by scientists to describe the age in which human activity has become the dominant force shaping the biological, geological, and atmospheric processes of our planet.

At the Aarhus School of Architecture, two communities—the Architectural Research Centers Consortium (ARCC) and the European Association for Architectural Education (EAAE)—have come together for our twelfth joint international conference. Since 2002, these biennial conferences have brought together researchers, educators, and practitioners to exchange ideas, reflect on research findings and methods, and discuss pressing topics related to architecture and the built environment.

The 2024 EAAE-ARCC Conference theme, Architecture into the Unknown, is more timely than ever. In the face of today's challenges, change is essential: in how we design and build, collaborate as societies, and live our lives. To be an agent of change is to care—care for others, for our communities, and for the biosphere. It also means taking action—not only for our own sake but for the well-being of all. We must also recognize that the challenges driving this need for change are, at the same time, profound opportunities. It is time to seize these opportunities—to act creatively, decisively, and with critical optimism—by embracing new, sustainable, and ethical approaches and ensuring they are accessible to all.

I wish to thank the Aarhus School of Architecture, especially its conference chair, Claus Peder Pedersen, and the entire organizing team for hosting us so generously. I also thank my colleagues at ARCC and EAAE, and all of you who are committed to working toward a better future and the well-being of all through architectural research and education.













Photos: Niels Rysz Olsen

CHAIR'S REPORT: ARCHITECTURE INTO THE UNKNOWN

CLAUS PEDER PEDERSEN, CONFERENCE CHAIR

INTRODUCTION

This report offers a short overview and reflection on the **Architecture into the Unknown** EAAE–ARCC Conference 2024. Its aim is to highlight the main ideas, discussions, and moments that shaped the event, to provide a sense of what unfolded over the days the participants spent together, and to acknowledge the collective work that made it possible.

The conference set out to open new conversations in architectural research by bringing together different cultures of inquiry and collaboration. As the biannual joint research conference of the EAAE and ARCC, it brought into dialogue two organisations with distinct yet complementary missions.

The European Association for Architectural Education (EAAE) is an international network of European schools of architecture committed to advancing the quality of architectural education and research across the continent. It provides a forum for shared discussion, exchange, and policy-building, promoting the interests of architecture schools as academic environments and fostering connections that strengthen architectural education and scholarship in Europe.

The Architectural Research Centers Consortium (ARCC) is an international association of research centers, academies, and organisations dedicated to advancing architectural research. Through conferences, grants, workshops, and its journal **Enquiry**, ARCC promotes scholarship that contributes to improving the built environment. Its community includes architecture schools with established research programs, as well as industrial laboratories, government agencies, non-profits, and private practitioners, collectively supporting a broad research infrastructure for the discipline.

Through the ongoing collaboration between these two organisations, the conference brought researchers from Europe, North America, and many other regions into a shared space where contrasting methods, priorities, and perspectives could meet. Under the theme **Architecture into the Unknown**, the event encouraged participants to explore how architectural research can navigate—and respond meaningfully to—the rapidly shifting social, environmental, and technological challenges of our time.



Photo: Niels Rysz Olsen

CONFERENCE THEME

The conference title **Architecture into the Unknown** reflected an intention to examine how architectural research can respond to the profound transformations currently reshaping the discipline. Architecture today confronts a series of interlinked challenges such as the accelerating impacts of climate change, pressures on material and spatial resources, increasing demands for social responsibility and accountability, and the emergence of new digital and computational tools. These developments raise fundamental questions not only about disciplinary boundaries, design methods, creativity, and authorship, but also about how architectural education can prepare future practitioners to engage with rapidly changing societal, environmental, and technological conditions.

The call for papers addressed six topics, each corresponding to an area in which these contemporary challenges are particularly evident:

Sustainable Architecture. This topic invited contributions that engage with environmental pressures on architectural practice—potentially examining climate adaptation, resilient design strategies, circular economy principles, or ecological perspectives. The intention was to explore how environmental awareness might be integrated more systematically into design approaches and disciplinary thinking.

Innovative Materials and Construction. Here, the call sought research exploring new material practices and construction systems. Possible areas of inquiry included renewable or bio-based materials, retrofitting and reuse strategies, design for disassembly, or the implications of digital fabrication. The topic encouraged reflection on how technological, economic, and resource-related shifts are reshaping the material and technical foundations of architecture.

Ethics and Social Responsibility. This topic invited proposals addressing the expanding ethical dimensions of architectural work. Authors might explore issues of inclusivity, accessibility, social justice, environmental stewardship, or the ethical implications of AI and data-driven tools. The aim was to foster discussion on the social obligations and responsibilities embedded in architectural decision-making.

Disciplinary and Interdisciplinary Approaches. The call encouraged contributions examining how architectural knowledge interacts with other fields, such as engineering, ecology, the humanities, or social sciences. Proposed work could address the opportunities and challenges of integrated or transdisciplinary approaches or investigate how disciplinary boundaries are shifting in response to complex contemporary problems.

Future Architectural Education. This topic focused on how architectural pedagogy is evolving in light of technological, environmental, and societal change.

Proposed contributions might explore new educational models, sustainability-oriented curricula, emerging technologies in teaching, or the skills and capacities future architects will require.

Open Category. This category provided space for proposals that did not fit neatly within the predefined topics but were relevant to the overall aims of the conference. It allowed contributors to introduce perspectives that expanded or challenged the thematic framework.

Applicants were invited to address the topics through several distinct contribution formats. **Papers** formed the central academic component, offering opportunities to present theoretical analyses, empirical studies, methodological developments, or examinations of educational practices. **Posters** provided a visual medium for communicating ongoing or recently completed research projects, enabling concepts and findings to be conveyed concisely through graphic and illustrative means. **Explorative Practices** was a new format introduced for this conference, designed

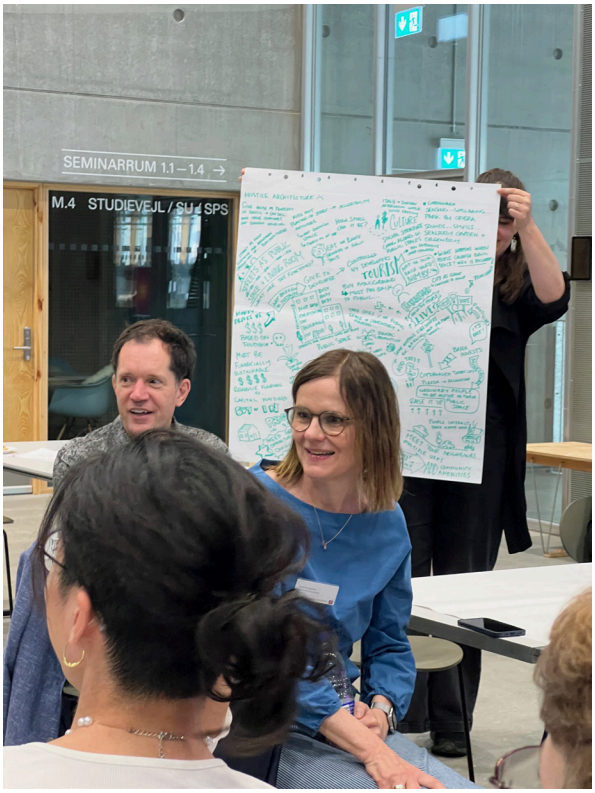


Photo: Claus Peder Pedersen

to accommodate alternative modes of inquiry. This format encompassed artistic, educational, participatory, and co-creative approaches that could take the form of artefacts, installations, performances, or workshop-based activities, offering perspectives not easily captured through conventional academic papers.

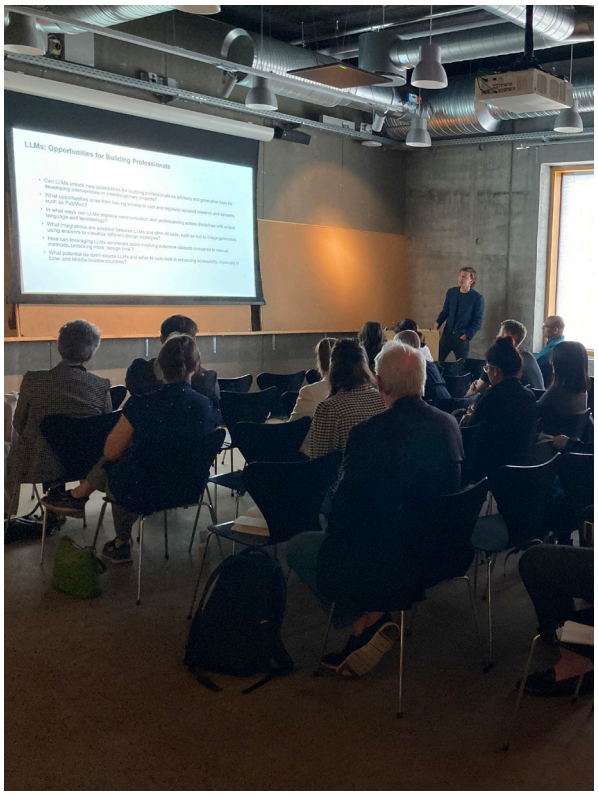


Photo: Naime Esra Akin

PEER-REVIEW PROCESS AND CONFERENCE PLANNING

The conference drew strong engagement from the wider architectural research community, with a total of 330 abstracts submitted: 290 papers, 15 posters, and 22 explorative practices. During the initial peer-review stage, each contribution was reviewed by two reviewers from EAAE and ARCC. This resulted in the acceptance of 179 abstracts—158 papers, 7 posters, and 12 explorative practices—which were invited for full submission. The full papers and explorative practice proposals were again reviewed by two reviewers, while posters did not undergo a second review. This process led to the final acceptance of 98 contributions, comprising 88 papers, 5 posters, and 5 explorative practices.

These figures correspond to an overall acceptance rate of 29.7%. Acceptance rates differed across formats, with papers accepted at 30.3%, posters at 33.3%, and explorative practices at 22.7%. Together, these patterns reflect both the breadth of interest in the conference themes and the selectivity of the review process.

The call proposed organising the conference sessions around three modes of inquiry: **Observatories**, focusing on broad societal or historical perspectives; **Laboratories**, centred on defined questions, tools, or experimental methods; and **Studios**, highlighting creative, practice-based, or pedagogical work. This model was intended to encourage encounters

across subdisciplinary boundaries by grouping presentations according to their conceptual orientation rather than their subject matter. However, as planning progressed, it became clear that combining this framework with the six topical categories and three contribution formats proved too complex. Many submissions spanned multiple themes and approaches, making it difficult to assign them coherently within a rigid three-perspective structure.

Consequently, sessions were organised according to the topics of the submissions, while the curatorial intent behind the original framework informed the grouping of contributions. Because many papers crossed thematic borders, the organisers took care to identify shared questions, methods, and concerns across the diverse proposals. This deliberate curation aimed to bring related perspectives into dialogue and to encourage participants to encounter work that complemented or challenged their own.

The final programme reflected a broad distribution of contributions across the six topics. Seven sessions addressed Sustainable Architecture, including one dedicated to explorative practice. Innovative Materials and Construction and Ethics and Social Responsibility were each represented by five sessions, while six sessions focused on Disciplinary and Interdisciplinary Approaches. The theme of Future Architectural Education comprised seven sessions, again with one devoted to explorative practice. In addition, two sessions combined themes—one linking Innovative Materials and Construction with Ethics and Social Responsibility, and another bridging Disciplinary and Interdisciplinary Approaches with Future Architectural Education. Finally, two sessions were organised under the Open Category, both dedicated to explorative practice.



Photo: Stefan Darlan Boris

THE CONFERENCE

The **Architecture into the Unknown** conference took place from 23 to 26 May 2024 at the Aarhus School of Architecture, which provided an environment characterised by artistic exploration, scientific inquiry, and practice-based learning. This atmosphere supported the conference's ambition to bring together diverse research cultures and to explore how architectural knowledge is produced, shared, and transformed across different contexts.

The conference programme was designed to reflect—and actively support—the multiplicity of approaches shaping contemporary architectural research. The large number and diversity of submissions illustrated the breadth of orientations, theoretical perspectives, and creative practices currently at work in the field. Participants represented a wide spectrum of academic, pedagogical, and practice-based engagements, offering a multifaceted view of how architectural knowledge is being articulated today. The richness of this material was further emphasised by the thematic overlaps between contributions, which revealed a discipline reassessing its ideals, methods, and responsibilities. Curated session groupings made these overlaps visible, enabling participants to navigate connections between environmental, social, technological, and educational concerns and to engage in conversations that extended beyond their immediate areas of expertise.

These ambitions were realised through an intensive four-day programme that brought together the conference's multiple components in mutually reinforcing ways. The programme featured **eighty-eight peer-reviewed papers and four explorative practice presentations,** distributed across **thirty-four thematic sessions as well as four poster presentations**. **Three keynote lectures,** and **three workshops**. This structure allowed participants to encounter a broad range of topics, formats, and modes of inquiry—from theoretical reflection and empirical analysis to creative experimentation, technical development, and pedagogical innovation.

Keynotes

The three keynote lectures provided shared framing points for the conference discussions. Conceived to

address the theme from different vantage points, they bridged academic research and professional practice and highlighted how future architectural approaches may evolve through material innovation, transdisciplinary collaboration, and sustained attention to environmental and social conditions.

Anders Lendager presented an approach to architectural practice centred on circularity and radical material reuse, demonstrating how new value chains



Photo: Claus Peder Pedersen

and technologies can emerge directly from design experimentation.

Alexandra Arènes showed how landscapes can be read and represented through transdisciplinary collaborations, inventive mapping techniques, and close attention to planetary processes.

Günther Vogt reflected on how landscapes can be interpreted and shaped through observation, material knowledge, and interdisciplinary cooperation, offering insights into future forms of urban coexistence.

Together, the keynotes expanded the conversation around architectural futures and underscored the value of connecting research, practice, and education when addressing contemporary challenges.

Workshops

Three workshops complemented the conference by offering hands-on spaces for discussion, experimentation, and methodological reflection. They explored how architectural research can support more equitable, inclusive, and future-oriented design practices.

- **Spatial Equity and Inclusiveness in the City Centre** examined the societal and spatial dimensions of accessibility and inclusion, fostering debate on how research, education, and practice can contribute to socially resilient urban environments.

- **Rethinking Architectural Research: Spatial Agency Towards a More Equitable Future** encouraged participants to reconsider spatial agency through everyday scenarios, challenging conventional hierarchies in design and authorship.

- **From Data to Discovery: AI Tools for the Next Generation of Architectural Scholars** introduced emerging researchers to AI-supported methods for structuring and advancing architectural inquiry.

Despite their differences, the workshops shared several overarching concerns. All engaged with societal challenges and emphasised the need for more equitable and inclusive architectural environments. Each explored ways of expanding architectural agency—whether through participatory processes, new representational techniques, or emerging digital tools. A commitment to methodological innovation connected them, as did an interest in strengthening links between research and practice. Collectively, they aimed to equip emerging scholars and practitioners with the perspectives and capacities needed to navigate shifting environmental, social, and technological conditions and to contribute meaningfully to future architectural worlds.

The **Explorative Practice** contributions within the main programme served a related function, offering experimental, creative, and participatory approaches that paralleled the workshops' interest in alternative research methods.

The explorative practice contributions collectively highlighted experimental approaches that broaden how architectural knowledge can be produced. Several presentations investigated the potential of emerging technologies—such as microsensors, real-time modelling interfaces, and AI-assisted qualitative analysis—to open new ways of understanding

design processes, user needs, and complex datasets. Others foregrounded embodied and situated methods, including an interdisciplinary exercise that combined biological and architectural perspectives through a short field trip to the surrounding landscape. This session invited participants to engage in shared, participatory observations that heightened sensitivity to site conditions and more-than-human environments. Another contribution emphasised aesthetic and interpretative techniques, using collage and visual translation to explore architectural practice within the shifting conditions of the Anthropocene.

Across these varied methods, the presentations shared a commitment to hands-on experimentation, cross-disciplinary collaboration, participatory engagement, and new forms of representation and analysis. Together, they demonstrated how alternative research practices can complement conventional scholarly formats and offer fresh insights into contemporary architectural challenges.

CONCLUDING REFLECTIONS

Several recurring concerns emerged throughout the conference. One was the growing attention to social and environmental challenges and to the responsibilities these places on architectural research and practice. Another was the recognition that new tools, whether technological, representational, or participatory, are reshaping how knowledge is produced and shared. The explorative practice sessions highlighted how experimental methods and embodied, collaborative forms of inquiry can extend the reach of traditional research formats. There was also a consistent interest in how architectural education might evolve in response to these shifting conditions, and how emerging researchers can be supported in developing the capacities needed for an increasingly complex professional and academic landscape.

The curated organisation of sessions and workshops helped to create points of contact between contributions that addressed similar questions from different perspectives. These exchanges underscored the value of sustained dialogue across areas of expertise and highlighted the importance of building connections between research, practice, and education. The discussions also pointed to several areas in which further work is needed, including the development of shared vocabularies across disciplines, the integration of emerging technologies with ethical and critical frameworks, and the cultivation of research cultures that are both rigorous and inclusive.

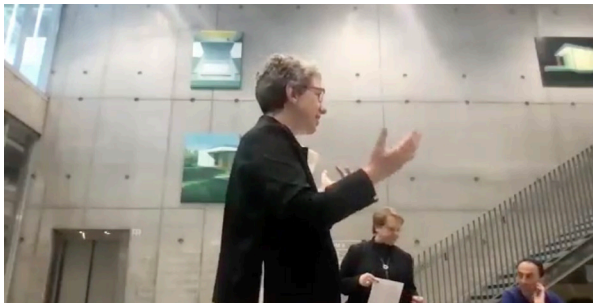
Overall, the conference demonstrated a strong collective commitment to expanding the scope and impact of architectural research. The conversations that unfolded across a community representing institutions from Europe, North America, and many other regions—reflected a shared willingness to engage with pressing issues and to explore new directions for investigation. As the field continues to respond to environmental uncertainties, technological change, and evolving social expectations, the conference affirmed the importance of collaborative, reflective, and critically engaged research practices. The insights generated during these days provide a foundation for ongoing dialogue and will continue to inform work within the community in the years ahead.



Photo: Naime Esra Akin

WORKSHOPS

CAN WE DESIGN THE FUTURE FOR BETTER SOCIAL EQUITY?






All images are stills taken from the workshop video provided by Alexandra Staub, 2024.

ORGANISED BY:
Architecture Research Centers Consortium ARCC

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"SO YOU WANT TO CHANGE THE WORLD? START BY CHANGING THE BUILT ENVIRONMENT."
(MASSEY 2012)

Our built environment exists at several interlocked scales: individual buildings shelter us, represent our aspirations, and mark our perceived place in the world; neighborhood systems offer identity and a sense of community, and cities connect us to larger needs such as economic opportunities, education, and health and recreation.

Planning the physical environment is left largely to professionals whose background and training are often technical rather than rooted in epistemic standards derived from conditions of humanity. Put another way, the professionalization of how we shape our built environment has gone hand in hand with a critical loss of regard based on an understanding of history and acknowledgement of social patterns and needs that determine our place in the world.

This workshop examined the role that stakeholders might play in physically shaping our environment, and with it the framework for cultural expression and social equity.

Participants were given a prompt from the essay "Five Ways to Change the World" by Jonathan

Massey, taken from the volume Where are the Utopian Visionaries: Architecture of Social Exchange. The three prompts selected were "Build a House", "Shop", and "Throw a Party". The reading focused on how everyday decisions can impact our built environment and how we live.

In a first example, Massey explored how, "houses […] provide the context for many consumption decisions and shape the patterns of daily life and intimate relationships." Massey then presented examples that promised liberation from convention. Buckminster Fuller's Dymaxion house, for example, provided resource efficiency but also promised social transformation through liberating users from, "the social and financial systems – above all mortgages – that bonded individuals in […] a form of serfdom." The Schröder House, commissioned by Truus Schröder for herself and her children in Utrecht in 1924[i] permitted its residents to, "define the degrees of intimacy or withdrawal they wanted [….] through moment-by-moment choices about how to live separately and together." Finally, a house designed by Rudolf Schindler in California in 1921 provided communal living spaces for two families (his own and another).

In a section that examined (primarily U.S.) shopping patterns, Massey showed that, "consumption offers a constant, vast, and extraordinarily nuanced vehicle of expression." Massey pointed to "Automats", self-service, vending-machine restaurants that flourished in many European and North American cities in the first half of the twentieth century and unexpectedly became accessible public venues that allowed marginalized populations spaces of refuge and even activism." Massey used "queer culture" as an example during a time when homosexuality was stigmatized or illegal. Today, our commercial transactions continue to impact the world: "The ways we produce and consume energy, food, goods, and the built environment have broad consequences for the future of the planet and society," while "individual expenditures aggregate to produce large outcomes."

In a section titled "Throw a Party", Massey examines a low stakes way to create social change. Pointing to the pageants, processions, and festivals of yesteryear that, "helped disparate social groups […] work together to govern the city and plan its future," Massey points to today's events that might be, "throbbing dance parties [that] create immersive, affective environments," as well as festive art parties, film festivals, and other examples of communal ritual.

After reading the text, workshop participants discussed ways in which housing, shopping, and public events could be used by architects and other stakeholders to improve social equity and inclusion. Participants were asked to brainstorm models for better social equity and determine what new opportunities for both design and research might look like. The following sections present reflections made in the three workshop groups.

HOUSING GROUP:

Our group noted that the reading is over a decade old and reflects situations prevalent in the United States, with its emphasis on the single family house – a housing form that will not remain sustainable for the twenty-first century. The examples in the reading – Buckminster Fuller's Dymaxion House, Gerrit Rietveld's Schröder House, and Rudolf Schindler's own house in California – were presented as iconic architecture that offered social opportunities. Our architectural education, however, tends to focus on the "iconic" nature of the buildings rather than the social opportunities they present.

We discussed how a key social issue continues to be the right to housing, a question that we need to address through policy and legislation. Even in countries where such policies are fairly well developed, for example through northern Europe's state subsided housing programs, more can be done. In some countries (for example the United States), housing is seen as a commodity. We asked ourselves: who has access to housing and how can we make it more accessible for all people? What should the future of housing look like? How can architects work towards substantial social equity changes to the built environment?

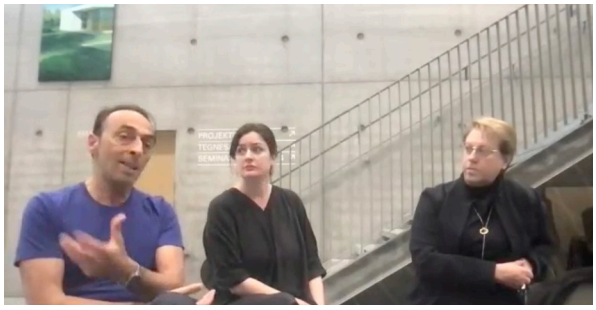
In many contexts, existing housing is too large for our needs, and in some cases, older housing no longer fulfills our needs. To better use urban space, we must think of ways to refurbish urban housing to meet today's standards. For example, we could make housing subdividable, we could swap housing if our needs change, or include shared amenities for children.

What should housing research questions be? Some that we identified: What is the role of legislation and policy in housing equity, what is the role of design, who is designing for whom? These questions led us to thinking about co-creation of both research questions and results. The community needs to be part of any housing discussion and that will require new organizational models.

We discussed organizational models for owning a house together, and building and transforming it together. In Denmark there is a program for non-profit affordable housing, which now makes up 20% of Denmark's housing market. The financing model is quite complex, and is based on the idea is that everyone is able to live in the housing, and no one makes a profit from it. The model is based on housing organizations that are governed by tenant democracy. Under this model, housing is not considered a capital investment, it's considered a home. We discussed the need for research on new organizational models for providing housing. We design housing, we design communities, and we can also design organizational models to better provide for and accommodate both.









All images are stills taken from the workshop video provided by Alexandra Staub, 2024.

SHOPPING GROUP:

Our group started with ideas of sharing. One way to support social causes is to make purchases with an eye towards shareability. We discussed sharing short-term housing (through online platforms) and vehicles (through car or bike sharing programs). We discussed the policies that are necessary to encourage sharing as well as bartering or swapping programs, where individuals don't purchase new items or services but trade them locally. Sometimes such programs increase social equity and sometimes they end up impoverishing the tax base and thus drain resources that can support social initiatives.

Many things happen "under the table" as part of a gig economy or on alternative platforms, and we discussed how policies can serve to educate, acculturate and legitimize alternative practices, such as bartering for goods or allowing surplus food or objects to be shared or given away. We discussed how it's important to keep these "markets" open and transparent. A solution might be to keep things local. This would allow people to get to know each other, too.

The reading discussed how certain types of sharing, such as the "Automat" restaurants, supported alternative cultures, such as the "queer culture" described in the Automat example. There's a feedback loop here, where a culture fosters a practice that then leads to a space that allows that culture to emerge and express itself. We discussed this phenomenon in terms of trust. When there is ethnic or racial bias, for example, trust needs to be built up, otherwise we run the risk of exclusion in certain spaces. Sharing is part of a system of trust-building.

Education is a key policy here as well – we must learn how to share, to build trust, and to avoid over-commercialization. Alternative spaces of consumption create alternative spaces of sociability. Shared kitchens, where a person cooks for a group, are one example of this phenomenon. Both social and material exchanges need to be rehearsed to allow for policy changes to happen. When we create spaces, they sometimes fill with life in ways that are unanticipated – we saw that in the Automat example presented in the reading.

Historical examples help us understand possible outcomes of spatial use, so one aspect of our research could be to better understand how spaces have been used socially in the past and why. There

are specific examples of communal thinking here: for example, in restaurants that provide free surplus food to the community. Another example is presented by the owner of the Flying Tiger stores in Denmark, who has bought several churches and opened them to provide free food to the community.

THROW A PARTY GROUP:

In our group, we talked about what defines celebrations and parties and quickly determined that different communities in different locations might have quite different views on what a celebration is. We defined "party" as a celebration of life with food, dance, music, etc. and thought about how we could make that accessible to all people. Based on the prompts given, we thought about how future generations might recreate, and what new opportunities for design, community offerings, and research might look like.

Recreation should be accessible to everyone. Recreation might involve going into the forest or countryside, but we also need recreational opportunities in urban neighborhoods. We discussed what recreational spaces in urban areas should be like and determined that such spaces should be flexible and adaptable and provide opportunities for people to meet. People must also identify with and feel "ownership" over the spaces they occupy in order to find relaxation there, so recreational spaces must provide a sense of identity. Public spaces can be commissioned. Part of a street, or parts of a square can be redefined and networked so that you can visit other recreational spaces but also have a recreational space in "your" neighborhood.

Aarhus is a good place to party. There are many beautiful urban spaces that invite people to socialize. To create recreational spaces, we can work with community organizations, local governments, or resident groups to redefine existing urban spaces or even seek out abandoned areas that might be reprogrammed. These kinds of projects create new opportunities for existing spaces.

In our group, we all focus on community-based research. We felt that whatever community you're in has something to offer to people both inside and outside the community, for example, nationality celebrations, food culture, etc. So, if there were different hubs with different types of celebrations, then people could move between the hubs. This would create a network of celebrations at different scales. This could lead into things like intergenerational support as well as support across neighborhoods or ethnic communities.

Research opportunities are abundant. We've made many proposals here, but we don't yet know how they will work. A community-based participatory-research model must include all members of a community. This type of research allows the community to weigh in on definitions. What is a party for the community? How do we better create social equity?

Those of us working in community research are very aware of the barriers that we sometimes create. We must work with the community to understand how to break down those barriers. This type of research could be done through narrative or graphic studies, or even quantitatively. It's important to update the research frequently because habits and patterns change – for example kids nowadays are online much more than in previous generations. We have to factor this into our research.

Finally, it's important to work with and not for the community. We have the technical knowledge, but community members have the social knowledge.

CONCLUSION:

A common thread in all three group discussions was the importance of involving stakeholders in any design process, be it housing design, community sharing platforms, or the design of recreational spaces. Workshop participants also stressed that research must engage the community in a participatory process and that representation must be carefully monitored to avoid research bias. The workshop groups presented an array of ideas for more equitable living, with flexible and shareable resources at their core. Finally, the groups emphasized that research, design, and policy decisions all factor into improving social equity – and that the built environment can work towards changing our world.

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ENDNOTES:

[i]Schröder commissioned architect Gerrit Rietveld to build the house; both client and architect worked on its design.

SPATIAL EQUITY AND INCLUSIVENESS IN THE CITY CENTRE

RESEARCH, EDUCATION, AND PRACTICE

ORGANISED BY:
Architectural Research Centers Consortium ARCC

Future of the City Centre Network

Council for Research and Innovation in Building and Construction: Working Commission in Architectural Design and Management

FACILITATORS:
Bob Giddings: Newcastle upon Tyne, North East England.
Silvio Melhado: São Paulo, Brazil
Ihab Elzeyadi: Portland Oregon, USA

SYNOPSIS:

Among present urban dilemmas is the social and cultural integration of diverse populations and responses to the barriers created by limited access to the critical elements of safe, healthy, and dignified lives. The focus of this session is the role of research, education, and practice in inclusiveness and generating spatial equity. The challenge of creating socially and environmentally sustainable places that are accessible to various communities lies at the core of critical research in the design disciplines. Research into spatial equity and inclusiveness in architectural education and practice is manifested in both process and product. In thinking about the conference theme, this workshop will engage participants in a lively debate around a set of conditions and provocations that will assist the development of a resilient city centre. The concept of universal access to city-centre facilities, regardless of social class, race, gender, or ethnic background, needs to be carried through to practice. Moreover, inclusion for some members of society can represent exclusion for others. Thus, there is a continuum from the producers of urban space in all its scales through to the users. The outcome of the workshop will be to elicit ideas, opinions, and different perspectives from the participants, and lay out a plan of action for a future research agenda.

ISSUES FOR DISCUSSION:
Environment – healthy places, sustainable spaces, infrastructure
Social Change – lived experiences, capacity building
Economic Challenges – to benefit society rather than capitalists
Movement – equity in transport
Culture – re-use of heritage buildings and spaces

INTRODUCTION TO CITY CENTRES:



Site of proposed Central Library Square, Newcastle Upon Tyne.
Photo by Bob Giddings, 2024.

Newcastle upon Tyne is the regional capital of North East England. Traditionally, land in the city centre has been owned by the citizens and administered on their behalf by the City Council. There has been incremental development, but by the end of the 20th century some areas had become intentionally neglected as leases for small businesses were not renewed, and property emptied. The local authority was setting up these areas for major redevelopment.

Concerned at the lack of public space for community use, researchers and practitioners provided designs for the re-use of this vacated land and property. Shown above is a square at the front of the new City Library. It includes premises for small local businesses and city centre housing. Microclimatic analysis demonstrates that external noise is reduced, as are wind speeds, while temperatures are increased to enable the extended use of the space.



Proposed Central Library Square, Newcastle Upon Tyne.
Rendering by Bob Giddings, 2010.

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Plaça del Poeta Boscà, Barcelona. Photo by Bob Giddings, 2024.

Literature during the COVID-19 period emphasised the significance of green spaces in city centres for people's physical and mental health. Library Square was therefore conceived as part of a network that included green spaces. While there is considerable greenery at the periphery of the city, it is important to bring it into the city centre as places of relaxation and respite. This will require a commitment by the local authority and central government to the community, including ongoing maintenance.



New HMRC Building, site of proposed Central Library Square,
Newcastle Upon Tyne.
Photo by Bob Giddings, 2024.

This is what is being constructed at the Library Square location. The building fills the area and will become the largest footprint of any building in the city centre. There will be no open space nor access for the public. Without consultation, the Council sold the land to an international speculator, who is a contributor to the political party of the recent national government. The building is intended for a government department that will move 2.5 miles (4 kilometres) from its existing location. The premises will continue to be owned by the speculator, to whom the government will pay rent.



Urban Bridge, São Paolo.
Rendering by Ihab Elzeyadi based on mass media images.

São Paulo is the largest city in Brazil and South America. The metropolitan area of São Paulo, with its 24 million inhabitants, is one of the most populous in the Americas and the fifth largest in the world. São Paulo's city centre development occurred mainly between 1900 and 1980. Government agencies, office buildings, large shops, cultural spaces, and residential buildings were built, attracting people from all over the country and from abroad.

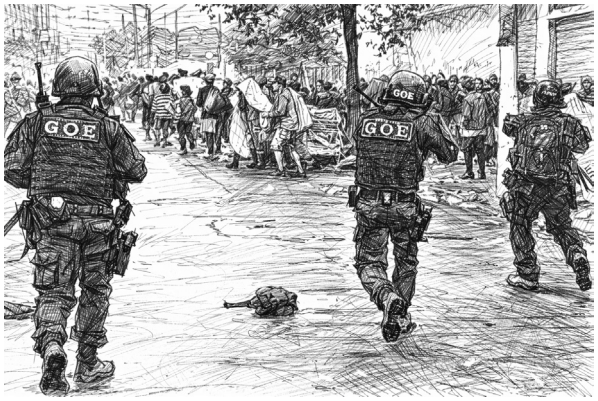


São Paolo Skyline.
Rendering by Ihab Elzeyadi based on mass media images.

São Paulo's city centre has several heritage buildings, protected by law, most of them from the modernist architecture movement. Famous examples include the Altino Arantes Building, also known as the Banespa Building (in the foreground of the picture above); the Municipal Theatre of São Paulo (1911); the 165-meter tower called Edifício Itália; and the Edifício Copan, one of the most emblematic buildings of São Paulo, designed by Oscar Niemeyer.

The public spaces of the city centre, previously valued and pleasant, have progressively lost their social and economic relevance as well as traditional commercial activities, thus alienating a large part of the population. Homeless people have progressively occupied sidewalks and squares, as well as abandoned buildings. The impact of overtourism, shopping, and cultural activities is enormous, giving rise to other social problems, such as vandalism, looting, violence, and drug dealing.

Social problems observed in São Paulo's city centre include the permanent presence of hundreds of crack and other drug addicts, in an area known as Crackland. It started during the 1990s and is still ongoing. The existence of Crackland in the city centre has led to a feeling of insecurity and, most importantly, worsened the deterioration of public spaces in the area. Most people pass through only because of transportation needs, as the main public lines originate in the city centre.



GOE Officers, São Paolo.
Rendering by Ihab Elzeyadi based on mass media images.

In recent decades, social and healthcare services have been provided for the addicted population, as well as police interventions attempting to control criminal activity. These approaches have alternated in an attempt to eradicate Cracolândia and return the use of public spaces to the rest of the city's population, although there have not been any effective results. Groups of drug dealers and addicts have moved from one area to another, without ever leaving the city centre.



Jamison Park, Portland, Oregon. Photo by Ihab Elzeyadi.

Moving on to a different setting and place, Portland, Oregon has been known as a rich urban setting with human-centric public spaces that are considered a model of public engagement in the US Pacific Northwest. With several squares, parks, and public playgrounds, Portland provides a multitude of public and accessible urban centres. These range from public places for social gatherings to places for local commerce, such as the Saturday Market, political demonstrations, and holiday celebrations that are relevant to ethnic and diverse cultural groups.

These accessible and affordable public places found new users and uses during the COVID-19 pandemic. They served as socially distanced gathering places, vaccination centres, public health check-up sites, as well as food supply pantries. These examples were great testimonials to the importance of flexible and accessible public spaces in the city centre that provide multiple uses and are open to different groups.



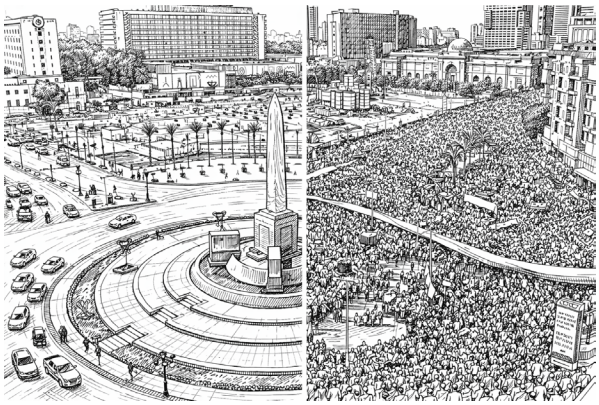
Pioneer Courthouse Square, Portland. COVID-19 Social distancing.
Image byTravel Portland Web Documentary.

This open and accessible space can be subject to abuse as well. We have witnessed how commercial activities hijacked such spaces during the COVID-19 pandemic and established outdoor cafés and restaurants in them. This has turned the space – once open and free to public use – into a space that is used for commercial purposes, excluding those who cannot afford to use these commercial establishments.



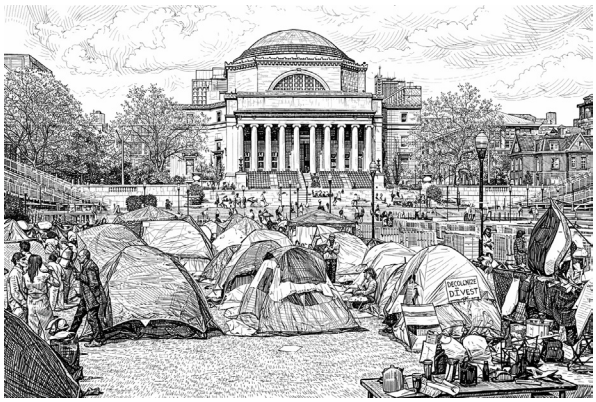
Piazza della Rotonda, Rome. Photo by Ihab Elzeyadi.

On the other hand, public space that does not belong to a specific group or entity can be left to a government that imposes strict rules and makes infrastructure changes to limit public use. The infamous Tahrir Square in Cairo, Egypt, was the main site of the 25 January 2011 revolution as part of the Arab Spring. It was later barricaded and reduced to a turnaround for vehicles with no pedestrian access, to curb any possibility for public gatherings.



Tahrir Square demonstration (Arab Spring).
Rendering based on mass media images by Ihab Elzeyadi.

Similarly, public areas and quadrangles on multiple US college campuses have been sites of demonstrations and political encampments by students and university staff to voice disagreements with US and college-campus policies. These public sites are used as spaces to make some student groups' demands more vocal and visible. They have also been sites of clashes with campus police, college administrators, and political far-right groups.



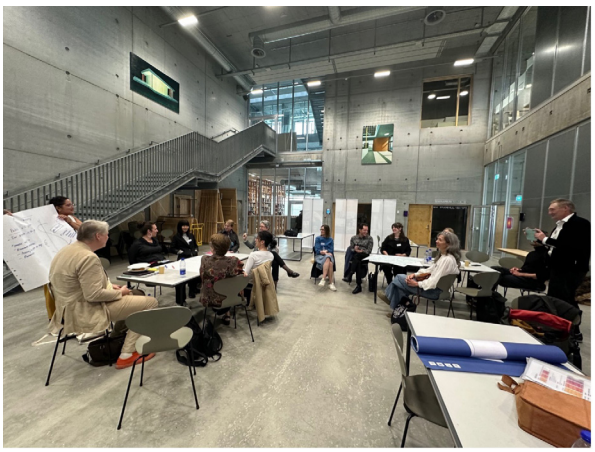
Columbia University encampment.
Rendering by Ihab Elzeyadi based on mass media images.

The above examples were intended to provoke a discussion about the dichotomy and challenge of city centre public space. Who is it for, who owns it, who manages it, and for what purposes? How can we ensure that its flexible and accessible nature is not abused by some groups at the expense of others? What set of rules and regulations can ensure its continuous use and generate spatial equity? These are some opening questions. The group participants were invited to debate them and generate actionable items for follow-up.

THE WORKSHOP IN ACTION:







Spatial Equity and Inclusiveness Workshop at the EAAE-ARCC 2024 Conference.
Photo by Ihab Elzeyadi, 2024

OUTCOMES FROM THE WORKSHOP:

Housing

Hostile architecture
How do people live?
Homeless
In Brazil as an example – houses are viewed as property, buying and selling, not enough housing.

Public Space

Inventory and mapping of city space needed – what proportion is public?
For cultural development, social structures are required alongside public spaces.
If land is sold to developers, it is controlled by developers.
Public ground must offer payback to the public.
Not totally public nor private but hybrid as a reinvention to improve health.
Space needs programmes to generate opportunities for connections.
People interact in parks – meet your neighbours, become involved in multiple uses.
Add trees.
Eat the plants that can be grown in public space
Parks are closed at night for the general public and homeless.
What happens when people colonise public space?
Who is excluded?
Copenhagen–sensing, well-being, park by the Opera, sounds, smells, sensory garden, green city, piazza recreation, bank invests for ordinary people to be active.
Italy – Sunday afternoon walks with family

Streets

They can act as public spaces and outdoor living rooms
Streets are the first element for children, growing up and playing there
Kids are not playing on the streets anymore – accessibility
Streets are now for moving cars not people

Funding

Revenue funding versus capital funding
Must be financially sustainable
City change is based on funding – money driven – who has buy-in?

Changing Demands

Previously argued that there is not enough space – density of use
Information technology – digital revolution
Do not need so much space, some functions are disappearing
Do not base everything on buildings
Invest in rental spaces and add community amenities
Over-tourism in some centres, especially historic cities in Europe
Public transit is increasingly important to reduce numbers of cars, vans and lorries

OBSERVATIONS AFTER THE WORKSHOP:

Isabel Potworowski

We seem to assume that public space is something that we are missing, while taking for granted that people want or need it. Do we need to re-evaluate what people's daily activities / lifestyles are, as we do with the clients of a house, to then determine what kind of public space they would benefit from?

There is a cultural aspect to public space. e.g. in Spain and Greece, people are out much later at night.

We tend only to talk about public space in terms of squares. What about streets, as places of meeting, as a living room for the city?

Who is the public when we speak of public space? Do we include the homeless and the disadvantaged? Is it truly public space if security (or more passively, furniture design) tries to keep them out?

Björn Lundell

To me the workshop opened my eyes to the large number of various aspects shaping the environments of today's cities. The conflict, the economy, the homeless etc. It interests me how local areas, squares, and streets together with local traditions (example: a Sunday afternoon walk with the family in Italy) build atmospheres for the people living there. How the people themselves organize and create the world surrounding them is possible as a way ahead. People can make the architecture live.



Drawing produced during the Spatial Equity and Inclusiveness Workshop at the EAAE-ARCC 2024 Conference by Cathryn John, 2024

EXPLORATIVE PRACTICE

Sensualizing, Interlinking, Anchoring – Research Collage as an Explorative Research Practice in the Anthropocene

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ABSTRACT: The Research Collage addresses the challenges of contemporary architectural practice. This implements the end of the environmental conditions of the geological epoch of the Holocene and the beginning of the Anthropocene. The aim is to investigate the multi-dimensional manifestations of architectural practice in place and time in the Anthropocene and thus to extend the scope of observation to processes beyond the architectural object. In order to overcome familiar thought patterns, the technical perspective of architectural production is complemented by the consideration of the aesthetic dimensions which is intrinsically tied to architecture. In addition to imparting tangible knowledge of architectural education, the research practice aims to create a framework in which students can transform knowledge in an exploratory way and thus develop their own approach to a new geological reality. The methodology developed operates at the interface of scientific research and the visual translation of knowledge. Three instruments are therefore implemented: The (1) media technique of collage uses architecture-specific representations to sensualise knowledge and enables the multi-dimensional linking of different places and times. The inherent (2) iterative design process of a collage stimulates associative relationships and facilitates a dialogue between the technical and the sensuous dimensions of architecture. The (3) *Threads of Thought* (*Process*, *Locality*, *Temporality*, *Scale*) provide a language framework to describe the multi-dimensional manifestations of architectural practice and anchor them in the Anthropocene. The resulting Research Collage is an epistemic artefact of the study of contemporary architectural practice and operates as a constant aesthetic echo of the scientific research.

KEYWORDS: Anthropocene, Collage, Research practice, Media, Knowledge transformation

INTRODUCTION

The impulse for developing this exploratory research practice is a well-known question that has been debated throughout the history of architecture: What are appropriate architectural arguments for the present? The question has usually been provoked by a change in the context of architectural production. Despite sometimes drastic social and economic changes, this has always taken place in the context of reliable environmental conditions. Accordingly, our building culture developed in the stable geological environment of the Holocene. Today, anthropogenic climate change in particular makes it obvious that these environmental conditions, and thus the context of architectural practice, are changing radically. According to earth system science, the changes are so profound that they speak of a new geological epoch - the Anthropocene. (Zalasiewicz et al. 2019) Therefore, a central challenge of contemporary architectural education is to explore the facets and dimensions of this new context, thus enabling students to develop contemporary architectural arguments.

1.0 PRESENCE AND CHALLENGE

1.1 Context - a new geological epoch

The Anthropocene thesis has been discussed by scientists from different fields of research for more than 20 years now. (Crutzen & Stoermer 2000) In 2023, the Anthropocene Working Group presented Crawford Lake (Canada) as a candidate for the Global Boundary Stratotype Section and Point (GSSP) of the Anthropocene Series. (Max Planck Institute 2023) Although the proposal was rejected and, in terms of stratigraphy, we are still formally in the Holocene (International Commission on Stratigraphy 2024) there is no doubt that the environmental conditions have changed radically. (Steffen et al. 2018, Richardson et al. 2023) The discourse on a new geological epoch has become a much-discussed topic in the natural sciences, the humanities and the media (Gasperoni 2022) and has turned into an essential concept of reflection in recent years. (Clark 2015)

The end of a geological epoch implies radical chemical, biological and physical changes in environmental conditions. (Zalasiewicz et al. 2019) This means: We are facing a context that is fundamentally alien to us. Although the Anthropocene describes a geological epoch, i.e. something "outside" the human scale, it identifies the sum of human activity as the cause of geological change. (Crutzen & Stoermer 2000) The concept of the technosphere, developed by Haff as part of the Anthropocene discourse, describe an environment in which the dichotomy between culture and nature largely dissolves. (Haff 2019) Consequently, the building culture is fundamentally entangled with the current and future environmental conditions. The starting point of the Anthropocene is estimated to be in the middle of the 20th century. (Max Planck Institute 2023) Thus, science is not describing an event in the distant past

or in the future, but an event in the present. With respect to the human impact on the Anthropocene, this means that the manifestation of the new geological epoch is shaped by our actions in the present. Depending on how we act in the present, different future scenarios are possible (IPCC 2021), where change is not linear but can be accelerated (or slowed down) by tipping points. (Armstrong McKay et al. 2022) In the context of a new geological epoch, it is inadequate to reduce the agency of architectural practice to the scale, temporality and locality of urban design, economics, construction, technological innovation and cultural-historical references. However, the radical novelty of the context makes it challenging to describe it with all its unprecedented implications (cf. Figure 1). Donna Haraway describes how alien this new environment is to us in her book "Stay with the Trouble, Making Kin in the Chthulucene" (Haraway 2018). At the same time, she invites us to "make kin" with the world anew. In doing so, she describes "making kin" as an active act of making connections between different actors (human and non-human), rather than a passive causality in the sense of genealogy. (Haraway 2018)

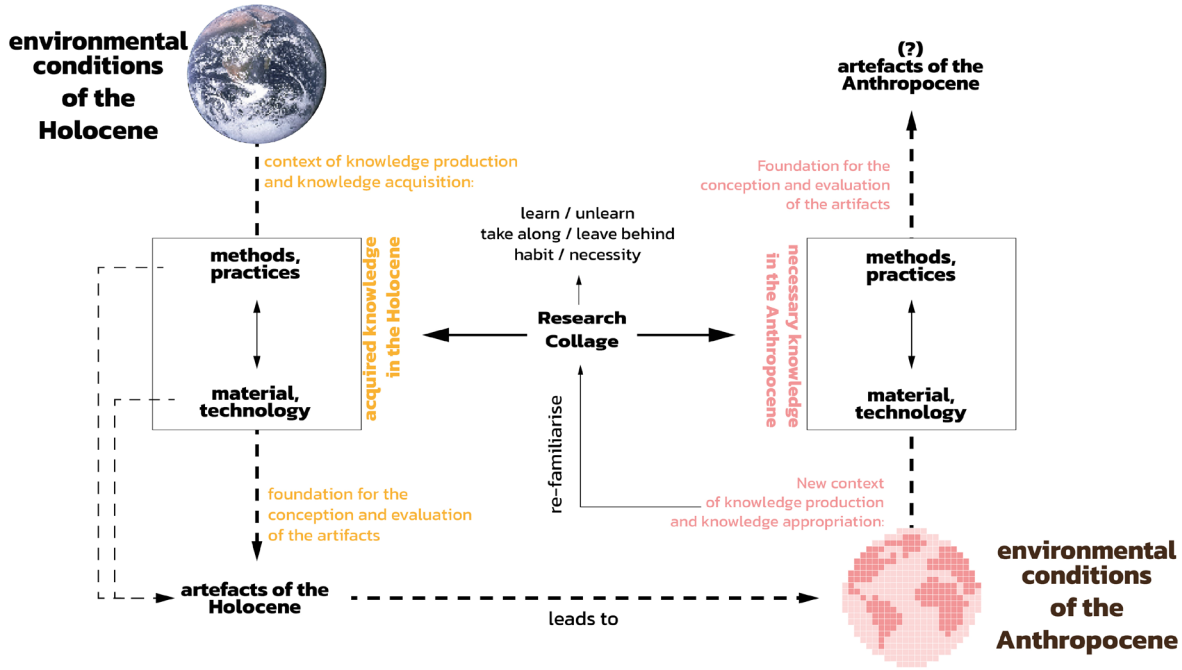


Figure 1: Re-evaluation of architecture practice in the context of the Anthropocene. Source: (Zihlmann 2024)

1.2 Sensualizing, interlinking, anchoring

Architecture, as a cultural practice and engineering discipline, unfolds at the interface of science, culture and art, manifesting itself as a sensuous reality in the environment. A building combines analytical as well as aesthetic and cultural dimensions and requires a multi-perspective view in its assessment. In the Holocene, we limited this consideration to the building itself. According to Haff, a building is a manifestation of the technosphere. (Haff 2019) Consequently, architectural production as a component of the technosphere cannot be considered independently of the lithosphere, the atmosphere, the hydrosphere and the biosphere. The concept of the technosphere aptly describes the interlinking of culture and technology with geological processes and expands the scope of architectural practice. As a result, architectural practice manifests itself not only as a sensuously perceptible reality in the form of a building, but also as a sensuously perceptible reality in the form of the infrastructure and resource extraction necessary for its construction and operation. Limiting the discourse to the scale of the building excludes the immanent interaction of the building with the five spheres and the sensualising of these interactions. The interaction of a building with the five spheres, includes a multitude of processes in multiple temporal and spatial scales. Expanding the scope of observation thus poses the challenge of describing and interlinking the multiple manifestations of architectural practice in place and time and thereby anchoring them in the new environmental conditions of the Anthropocene (cf. Figure 2). Morton describes this interconnection of processes in his book “Hyperobjects: Philosophy and Ecology after the End of the World" (Morton 2013), and Clark accurately describes the field of tension in which we operate in the present with the term "clash of scale". (Clark 2015)

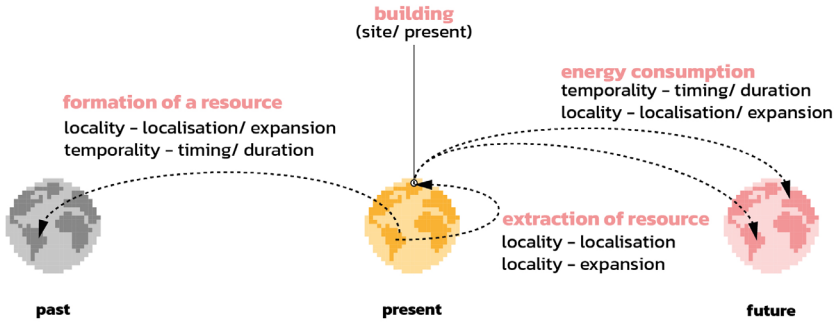


Figure 2: Multidimensional manifestation of architectural practice Source: (Zihlmann 2024)

Architectural practice in the Holocene has focused primarily on the object in the "here and now" and on a human scale. As a result, we lack the awareness and the vocabulary to describe multi-dimensional and multi-scalar manifestations in different spheres. The challenge of negotiating architectural arguments therefore lies, on the one hand, in the complexity of the discipline itself, and on the other hand, in the expanded perspective of the present. A radical transformation of architectural practice is therefore not only carried out along technical, normative, legal and material aspects but requires a re-embedding of architectural practice in the Anthropocene. In order for a radical transformation of building practice to be successful and empowered to act in the Anthropocene, we need architecture-specific methodologies and tools to consider and negotiate the aesthetic expression of the building as well as the aesthetic manifestation of all the processes involved.

2.0 EXPLORATIVE RESEARCH COLLAGE

2.1 Aim of the explorative practice

The Research Collage serves as a methodology to establish an aesthetic approach to an environment that has become alien to us. While students gain tangible knowledge of architectural issues, a framework is created in which they can work exploratively to familiarise themselves with the Anthropocene. Hence, the explorative practice does not aim to develop a solution to a specific technical problem, but to develop contemporary narratives by exploring architectural practice in the Anthropocene. To this end, the research practice operates at the interface of nature sciences and cultural studies, applying design-based processes and architecture-specific tools and media. They are used to investigate the effects of architecture in the environment rather than to design an architectural object. The process of (visual) transformation of knowledge provokes an aesthetic confrontation with the multi-dimensional manifestation of the object of investigation and serves as a framework to sensualising, interlinking an anchoring their knowledge. Thus, intrinsic dimensions of the Anthropocene are illuminated and interlinked with subject-specific knowledge. In doing so, it complements the current technical transformation of the building industry with the aesthetic and cultural transformation of building practice. In this way, trusted methods of reflection which were assimilated in the Holocene are dismantled. The instruments of research practice are intended to stimulate the exploration of contemporary questions and encourage the contextualization and reassessment of familiar arguments.

2.2 Instruments of the research practice

2.2.1 Threads of thought

The *Threads of Thought* summarize implicit dimensions of the Anthropocene and become an instrument for a contemporary examination of architectural practice. They cover four terms: *Process*, *Scale*, *Temporality*, *Locality* (cf. Figure 3). They provide a conceptual framework to describe the multi-scalar processes and manifestations of the five spheres (cf. chapter 1.2) in their spatial and temporal dimensions (cf. Figure 4).

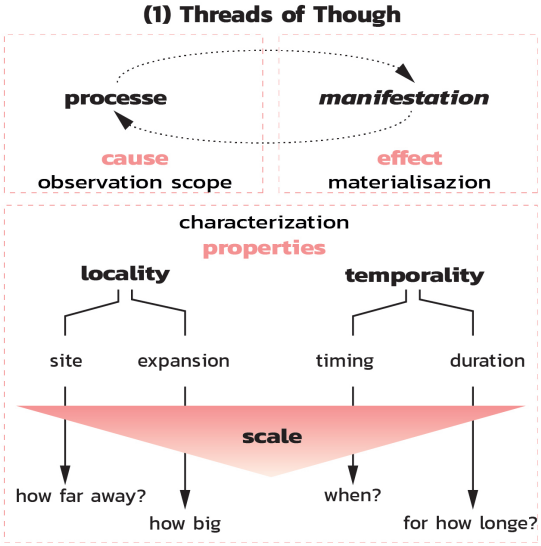


Figure 3: Systematics of the *Threads of Thought.* Source: (Zihlmann 2024)

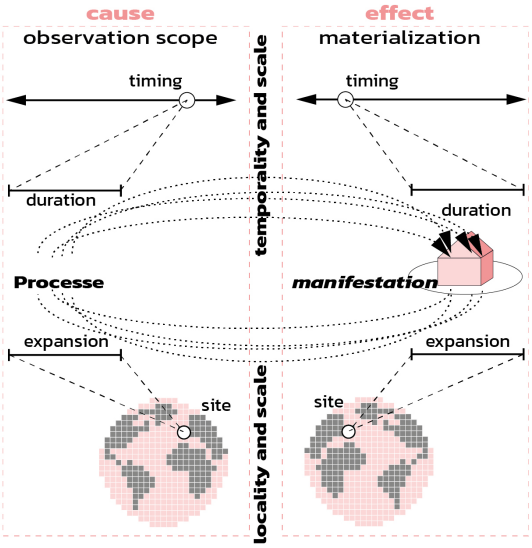


Figure 4: Dimensions of manifestation in the Anthropocene. Source: (Zihlmann 2024)

On the one hand, this allows specific processes to be interlinked; on the other, it allows the scope of observation to be broadened and anchored in the Anthropocene. In this way, they provoke an examination of the intrinsic agency of architecture in the present and encourage a break from the familiar human scale of the Holocene. The focus shifts from the building as an object to the multiple effects of architectural production in all five spheres.

2.2.2 Media technique of collage

A collage enables multi-scalar and multi-media work and requires an aesthetic engagement with the object of investigation, whereby it does not follow any clear normative guidelines. This allows an experimental transformation and interlinking of knowledge as well as the integration of aesthetic aspects of the manifestation. The Research Collage draws on a variety of visual media and tools from architectural practice (e.g. images, detailed technical drawings, pictograms and graphics, floor plans, spatial and atmospheric drawings). For the collage their individual qualities are exploited and enhanced by a textual layer. As a result, the collage provokes a translation of knowledge into visual and linguistic elements, thus making it sensuous. This can be achieved through representation, narration, comparison or translation into familiar units. The intrinsic quality of aesthetic translation to be precise as well as vague and associative allows for multi-layered readings and creates space for new relationships. It also allows for the simultaneous representation of processes on different temporal and local scales, which in a second step allows for the multi-dimensional interlinking of processes. The *Threads of Thought* serve to anchor the layer of observation in the context of a new geological epoch.

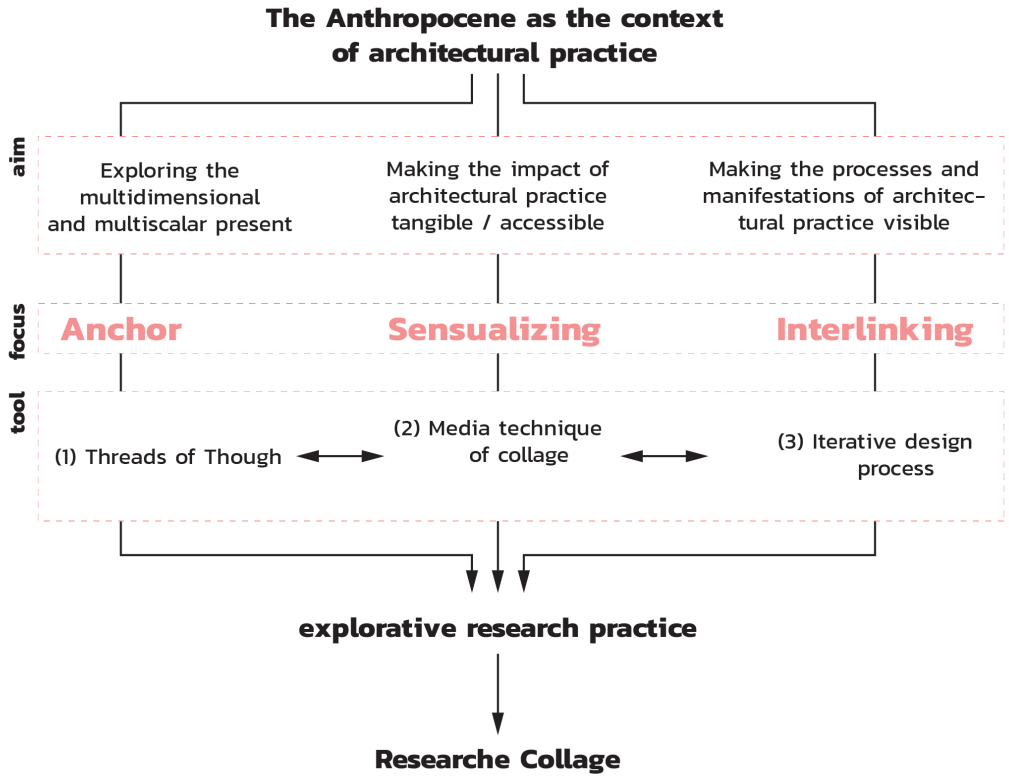


Figure 5: Methodology of the Research Collage. Source: (Zihlmann 2024)

In this sense, the collage technique offers a complexity beyond scientific data and creates a sensuous connection to the impact of architectural practice. Thus, while the Research Collage is capable of making visible the abstract and sensuous dimension of architectural agency. At the same time, it shifts the focus from the building in a stable and continuous environment (Holocene) to an agile fabric of processes in the Anthropocene.

2.2.3 Iterative design process

The dialogue between technical reasons and sensuous and cultural arguments typically takes place at the level of the building as part of the design process. Using the media technique of collage as a tool, the research practice can take advantage of this dialogue. In this way, the research practice does not aim for a linear process such as first defining a topic, then formulating a hypothesis, conducting the research and finally transcribing the results. Rather, it is a transformation of knowledge in which scientific research and the visual translation of knowledge follow an iterative process to overcome established patterns. In this way, the design process is applied as a "cognitive activity". This allows associative relationships to be established and adds (not replaces) a sensory and intuitive dimension to scientific research.

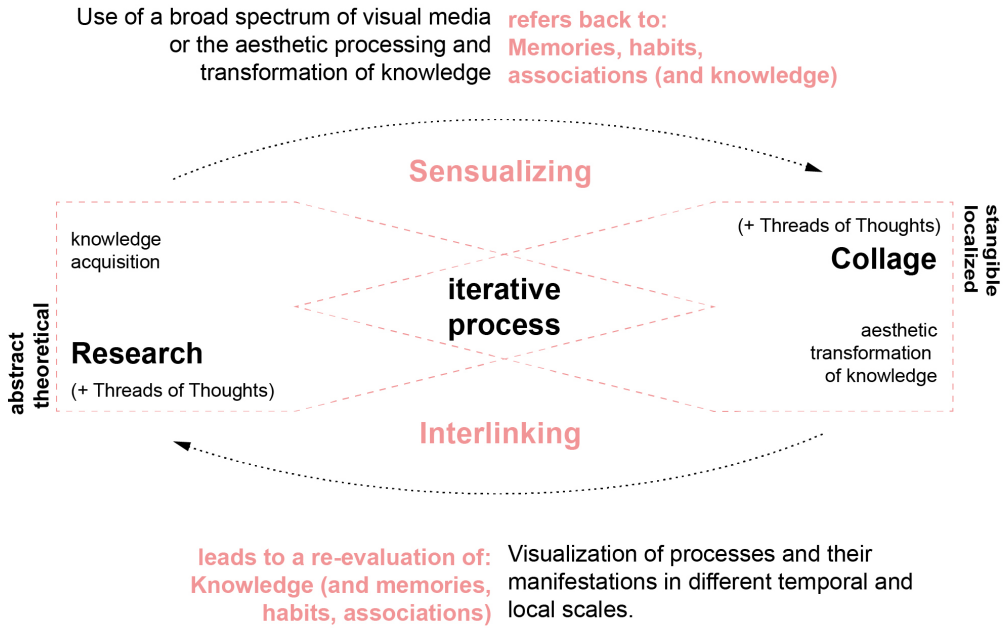


Figure 6: Explorative research process. Source: (Zihlmann 2024)

The Research Collage does not use the medium to represent a previously developed investigation, rather it is a permanent aesthetic echo of the scientific work. The collage itself provides a tool and is an epistemic artifact of the research process.

3.0 CASE STUDY – INBETWEEN INDOOR AND OUTDOOR CLIMATE

In the seminar, students work on different climatic building element each semester (winter 2022/23: window, summer 2023: roof, winter 2023/24: heat pump). The Research Collage is used to explore their agency in the Anthropocene. The seminar is structured as follows:

Table 1: Structure of the seminar. Source: (Zihlmann 2024)

Impulse lecture	Task (editig time)	Other elements
01 - Introduction to the Anthropocene thesis		Reading Session 01
02 - Introduction to aspects of the indoor climate	I.1 - Indoor climate (1 week)	
03 - Introduction to the explorative research practice	I.2 - Threads of Thoughts (1 week)	
04 - Introduction to aspects of the outdoor climate	I.3 - Outdoor climate (1 week)	Reading Session 02
05 - Introduction to the climatic building element	II - Explorative Research Collage (7 weeks)	
	III - Reflection/ Essay (2 weeks)	Reading Session 03 and Workshop

The five impulse lectures (cf. 01 - 05 in Table 1) provide an overview of the relevant topics. The preliminary exercises (I.1 - I.3) are conceived as a step-by-step introduction to the practice of explorative research. The explorative Research Collage (II) is the main element of the seminar and the reflection (III) allows students to reflect on their own approach and the (not) acquired knowledge. In the first task (I.1), the students choose a familiar room and investigate the room specific information relating to the indoor climate (e.g. geometry, façade and window area incl. building physics values, usage profile). This information is displayed in a spatial collage. The second task (I.2) operates with the *Threads of Thought* introduced in impulse lecture 03. The students develop two diagrams in which the *Threads of Thought* are applied to a particular material or object from the space selected in task I.1. The third task (I.3) explores the outdoor climate in the same way as the first task did. Therefore, the collage from task I.1 is to be revised and completed with the parameters relevant to the outdoor climate (e.g. position of the sun and angle of irradiation, surfaces/materiality of the environment). Following these three preliminary exercises, students start with the Research Collage (II).

CONCLUSION

Through the development of the Research Collage, students are introduced to the fundamentals of architectural practice. These fundamentals are considered in the multi-dimensional local and temporal context of the Anthropocene (technosphere, hyperobject) and discussed at the interface of scientific knowledge, cultural discourse and aesthetic manifestation. In this way, the Research Collage functions as a pedagogical practice to transform the understanding of the investigated element by sensualising and interlinking it and anchoring it in an environment unknown to us. The exaggerated demands of the research practice and the uncertainty of the "outcome" of the Research Collage are immanent components of the methodology and are intended to sensitize us to the complex and alien present. It is tempting to seek solutions according to familiar patterns established in the Holocene. However, the radically new environmental conditions represented by the Anthropocene require a critical and experimental openness to our building culture and environment, and a curiosity to explore radically new approaches.

ACKNOWLEDGEMENTS

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Fieldwork Across Disciplines – Six Phases Towards Another Situated Design Approach

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ABSTRACT: Urban planning and design face mayor challenges in mitigating environmental damages and restoring broken relationships between people and other living species. Interdisciplinary fieldwork (IDF), uniting landscape architects, biologists and other disciplines in co-investigation of urban sites, may open possibilities or deepening the human-nature relationship and motivating the necessary systemic transformative change. We tap into an understanding of 'sites' as comprised by thick and precious *networks* of heterogeneous actors (human and non-human, a-biotic and biotic) entangled in contextual *Critical Zones* where they collaborate over various timespans to create habitable conditions. Such an understanding calls for approaches to early-phase methodologies of recognizing the broad spectra of site-specific natural values and processes of life, to support them and coexist with them. Here, we discuss how practicing fieldwork across disciplines can create new situated sensitivity towards sites. Utilizing qualitative research methods, e.g. observation and interviewing, along with studies of documents, we explore and analyze the experiences with IDF in a nature-based design studio in Denmark. From the results we draw the contours of a framework for interdisciplinary exploration of project sites in an urban planning and design context.

KEYWORDS: interdisciplinary, fieldwork, nature-based solutions, critical zones, situated designing

1.0 RESEARCH PROBLEM AND CONTEXTUALISATION

1.1. Mapping manners matters

Urbanization and land use change must be acknowledged as a key driver of ecological change and biodiversity loss globally (Newbold et al. 2015; Seto, Parnell, and Elmqvist 2013).[1] Simultaneously an increasing 'extinction of experience' of nature for people living in urban environments corrupts human-nature relationships (Soga and Gaston 2016). Actors involved in development and design of urban environments face major challenges to mitigate this two-eyed problem. The manner in which sites prone for urban development or urban change are mapped and assessed may play a significant role in order to support ecosystems and generate sustainable urban natures (Lindholm 2017; Langner 2019; Spirn 2014; Mostafavi 2012). From the field of Landscape Architecture in Design Theory, we find a rich, unexhausted, literature on various approaches to site-analysis.[2] Such analysis can typically be sorted in two contradictory approaches (Simensen, Halvorsen, and Erikstad 2018), depending on two differing 'worldviews' and 'landscape concepts' (Hansen-Møller 2004; Holten-Andersen 2023); one based in natural sciences, the other in cultural sciences and arts. One utilizing and quantitative data and concerned with production of facts, the other utilizing qualitative data and concerned with production of narratives (Holten-Andersen 2023, 134–48). However, the present ecological challenges of urban development require weaving of environmental and cultural literate narratives of the city, and thus the cooperation of multiple disciplines (Hagan 2014).

1.2. Bridging the map

Based in the Natural Sciences, biologists most often take a quantitative approach to understanding the ecological state and function of a site (Kiers et al. 2022), but may struggle to engage and connect with other disciplines and the wider public. Acknowledging the human-nature relationship in planning and design for biodiversity, and broadening the focus beyond nature's intrinsic values by considering senses, beauty, emotions, meaning and compassion may resonate more strongly with people (Richardson et al. 2020; Chan et al. 2016). As the current human–nature relationship has become dysfunctional, it can only be restored through a co-creative partnership with nature, which calls for *localized* and *ecologically literate* practices of design, embedded in site-specific contexts of social–ecological narratives (Du Plessis and Cole 2011). Multiple recent concepts within urban planning and design (such as Nature-Based Solutions, Biophilic Design and Regenerative Design), push for design-approaches that support multiple lifeforms (Panagopoulos, Sbarcea, and Herman 2021). However, in order to design *with* the specific actors on a site, designers as well as researchers must be able to get to know them (Tsing 2015, 159). Existing methods of mapping within disciplinary silos fail to provide a comprised understanding of the site-specific networks of life, their performances, interdependency, and criticality.

1.3. Situated mapping in the Critical Zone

In order to bridge the disciplinary stances in site analysis, the view on the object of analysis comes into question (Olwig et al. 2016). Concepts of nature / place / landscapes / environments etc. is laden with nature-

culture dichotomy. To deepen the concept of 'site' and 'situation', we lean on the concept of the Critical Zone[3]. Critical Zones denotes:

> …a complex, dense world, filled and folded, crowded with entities and processes, movement and transformation, activity and signs, whose powers and conditions of existence are hard or impossible to disentangle" (Szerszynski 2020, 344)

According to Latour, the concept of Critical Zone encompasses a pledge to provide a new form of situated knowledge and "the effort of gaining a new proximity with the situations we have to live in." (Latour 2020, 9). Approaching a project-site as a Critical Zone entails comprehending it as an evolutionary system (Prominski 2005), that cannot be assessed as a 'container' in which life can unfold, because space is constantly reproduced by life (Arènes, Latour, and Gaillardet 2018).

1.4. Towards new knowledge

During the past decades the concepts of Situated Design, Co-Design and Participatory Design has affected landscape architecture and planning (Simonsen et al. 2021; Primdahl et al. 2010). These concepts acknowledge architecture and design as processes, produced in collaboration of numerous temporal actors, thus challenging the notion of the architectural 'work' (Albertsen 2013; Beim 2005). Building on Donna Haraway's understanding of situated knowledges (Haraway 1988), Arne Næss' conception of Deep Ecology (Naess 2005) and the before mentioned concept of the Critical Zone - we seek to explore Another Situated Approach, where matter and multispecies of a site participate actively in the design process. Future knowledge systems require interdisciplinary collaboration (Fazey et al. 2020), so do the study of thick networks on sites, prone for 'development'. Moreover, it seem sensible to use all imaginable 'learning practices' (Tsing 2015, 159), when researching deep landscape stories of sites. In this article, we seek to contribute to the study on methods of fieldwork combining cultural and ecological perspectives, which has been somewhat overlooked (Elmqvist et al. 2013, 730).

1.5. Research question

In this exploratory practice research, we investigate and discuss how practicing fieldwork across disciplines may create enhanced sensitivity towards sites. We explore an example of IDF-practise and ask how the empirical evidence may display certain characteristics of IDF and perhaps point towards a methodological framework for IDF.

2.0 METHODS

2.1. Case

As data-source for this Exploratory Practice Research, we investigated the use of IDF in the company SLA, based in Denmark and Norway (SLA 2024). The studio has worked in both research and practice for 30 years. SLA works with nature-based design and biodiversity in both urban planning, urban spaces and landscape architecture. The studio is internationally renowned for their visions, plans and designs. SLA aims to be a learning and interdisciplinary organization, consisting of e.g. anthropologists, architects, urban planners, biologists, geographers and communicators (SLA 2024).

2.2. Data

We analyzed three existing documents touching upon interdisciplinary fieldwork in the office of SLA. Furthermore, we have observed, recorded and produced field notes on two workshops considering interdisciplinary work at SLA. As supplement to the information gained from these sources, we have conducted a semi-structured interview with a biologist employed at SLA on her yearlong experience with IDF in the company. Table 1 offers an overview of the data informing the research.

Table 1: Data overview. Source: (Holten-Andersen and Engemann 2024)

Activity/Document	Date of assessment	Datatype	Data in text reference
Interview with Kim (pseudonym), Biologist at SLA	January, 2024	Video-recording / transcription	(INT, time of statement in recording)
Interdisciplinary fieldwork workshop at SLA, 2023	December, 2023	Audio-recording / notes	(IDFW1)
Interdisciplinary co-work workshop at SLA.	September 2023	Fieldnotes and imagery	(IDFW2)
Nine pioneering actions towards Another Green World. / Report from SLA Interdisciplinary camp 2023	December 2023	Illustrated report	(IDCP)
Introduction to Method Course	January 2024	Video available at SLA intranet	(IDMC, time of statement in recording)
Naturens værdi og den økocentriske by	August 2023	Book chapter in "Tænk os om – alternativer til Lynetteholm" published by Strandberg Publishing, Copenhagen.	(Andersson 2023)
www.SLA.dk	January 2024		(SLA 2024)

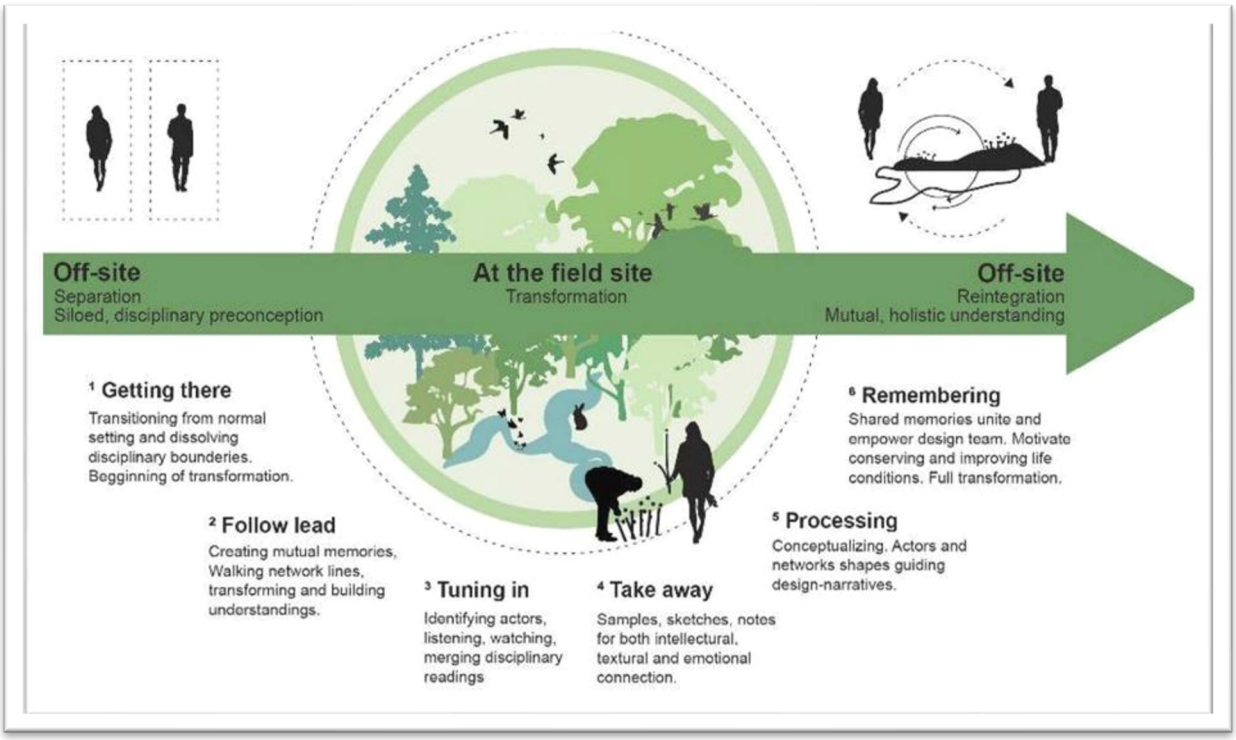


Figure 1: IDF framed as three stages (A. Separation B. Transformation, C. Reintegration) and six phases (1. Getting there; 2. Follow lead; 3. Tuning in; 4. Take away; 5. Processing; 6: Remembering) Source: (Holten-Andersen and Engemann 2024).

2.3. Analyzing data, theorizing and reflecting

Our strategy for theorizing has been abductive and reflexive (Schwartz-Shea and Yanow 2012, 30–36), moving between data and theory to improve understanding. The way of arranging fieldwork in transitory phases by Christophe Girot[4], has inspired our way of analyzing the data and sorting the results. In the available data, we have therefore sought to distinguish different stages of IDF and bring forward what evidence the data gives on their activities and outcomes. We identified three stages and six phases, as demonstrated in Figure 1. Table 2 displays the concepts and reflections used when analyzing the data.

3.0 RESULTS AND REFLECTIONS

Here, we present some findings from the empirical evidence of IDF at SLA. Due to limited space, we arrange the findings along with direct reflections and interpretation. Initially we report and reflect on the overall usage and state of IDF at SLA, then we present data and reflections on the six identified phases.

3.1 No formalized interdisciplinary fieldwork

As highlighted in the case description, SLA aims to enhance interdisciplinary design work, integrating several disciplines, in all phases of developing projects (IDMC). To implement this ambition, an interdisciplinary method-course is made available for the employees. In this course, employees are given insight into the methodologies of biologists and anthropologists – including fieldwork, making sure that the competencies and methods are widely known in the company (IDMC). Still, there is not a formalized framework on how to do fieldwork together, nor a code of conduct regarding IDF in the company (INT, 1-5 min). However, both the interview, the two workshops (IDFW1-2) and the SLA camp 2023 (IDCP) revealed that IDF is often performed at SLA and considered most beneficial for the integration of disciplinary stances, when undertaken.

3.2 Phases of fieldwork

The data collected on performed IDF shows promising contours of an IDF-approach, but also reveals that further definition is needed. In the interview, Kim notes that ‘fieldwork’, in her view, is something clearly defined, and it signifies an organized process of data-collection. Kim explains that biological fieldwork follows a predefined method and often have to produce a specific product from the data collected (INT, 0-2 min). Kim states that she is not entirely familiar with the fieldwork methodology of designers, and Kim notices that fieldwork may foremost be the domain of biologists (INT, 10-12 min). Kim further suggests that this may also be a question of available resources (INT, 47-49 min). “But when you say “IDF”, it turns into something much less specific […] I reckon you rather talk about a collective site visit?” (INT, 0-2 min).

- The remarks from Kim reveals possibilities of enhancing IDF at SLA, through formalization. Formalization may afford IDF to be an accepted activity, which can be launched in project planning and allocation of resources. Next, we elaborate on the six phases of IDF.

Table 2: Reflective analysis of data through academic conceptual reflection. How we translate key concepts into the IDF framework. Source: (Holten-Andersen and Engemann 2024)

Concept	Meaning	Motivating
'Thinking-with' (Haraway 2016a)	To relate to other beings and actors when trying to understand them - both as "an attempt to counteract a mode of thinking about matter as dead and mere resource" (Lilja 2021, 394). To our understanding, 'thinking-with', also stresses the act of listening and an effort to follow along the line of thinking of the representatives of other disciplines.	Getting there Follow lead
'Tentacular' (Haraway 2016b)	To understand how IDF may help the team grow more 'tentacles' – a larger sensory apparatus – when doing site-research.	Tuning in Follow lead
'*Situated knowledges*' (Haraway 1988) '*Proximity*' (Latour 2020, 9) *'Localization'* (Boullier 2015)	To achieve deep knowledge from the specific contextual situation, by endorsing proximity to it. To 'localize' oneself, not just describing the situation from 'outside'.	Tuning in Take away Remembering
'Matters of concern' (Latour 2010) 'Acvively engage ourselves' (Prominski 2019)	The movement from observing sites as consisting of 'matters of fact', toward actively engaging with them as 'matters of concern'.	Tuning in Take away Remembering
'Deep Ecology' *'Ecosphere'* (Naess 2005) *'Complementarity of reason and emotions'* (Naess and Haukeland 2008)	The appreciation of the inherent value of all flourishing lifeforms and units of the ecosphere. The appreciation of the need for dielectics of emotion and reason inorder to gain deep insights and build care.	Getting there Tuning in Take away Remembering
'Actor-Network' (Latour 2005)	Informs our understanding of the non-human actors as symmetrically important and equally involved in the design process. Guides our way of understanding of how disciplinary representatives can *act with matter* and each other to generate sensitivity and insight into the life on site.	Take away Processing Remembering
Four Trace Concept (Girot 2009)	Guides our understanding on the how IDF may be organized in transitory phases.	Six phases of IDF
'Ritual Theory' (Turner 1967, 13–14)	Widens our understanding on the transitionary processes that might play out within IDF.	Three Stages of IDF: Separation, Transformation, Reintegration.

3.3 Getting there

Kim reports how stepping into the field is very different from meeting each other in a meeting room in the office. It seems to provide much more specific information (INT, 4-7min). Furthermore, it makes space for a more informal exchange of opinions and often leads to more open and learning conversations. Being in the field together seems to release potential tensions and constraints that often occupy attention in the start-up of projects. In the field, Kim describes, the talk is about the site and the proposed design intervention, not about who does what and when (INT, 4-6min). Kim experiences that being in the field is less busy than in the office, where meetings are often short and conversations pushed to be more defined (INT, (6-8 min). In the field, there is time and space for sharing immediate impressions and ideas. You are free to make statements, which no one will hold against you, but still may prove most valuable and defining for the design project.

- Getting there – means getting out of the office and going into the field, several disciplines at once. It allocates time and space for being together in the team.
- It seems to open a door to utilize intuition and improve the ability to 'think with' each other and the site.

3.4 Follow lead

From the method-course, an organizer reports how the employees went into the field, to try what it is like to do biologist fieldwork, thus taking on a different perspective on the site. This step helped awaken the sense of what interdisciplinary work can bring to the design process (IDMC, 1-3 min). Likewise, Kim states that it can be fruitful to do disciplinary fieldwork, simultaneously, at the site. Even though one wanders of and does the activities needed for one's own work, it is done in the presence of the other disciplines (INT, 18-19 min). This provides the possibility of collecting data at the same place and time, thus producing mutual memories linked to the data/ registers – with better possibility of cross-reading them. IDFW1 also displayed elements of 'following lead', and the report from SLA camp 2023 express how one group utilized strolling through the site as a manner of getting familiar with it, generating interlinked memories (IDCR, p. 21-22)

- Follow lead – means doing disciplinary fieldwork in each other's company. Displaying the methods and apparatus of one's discipline – becoming aware of the different competencies of 'reading the situation' available in the team.

3.5 Tuning in / growing tentacles

Kim acknowledges that some of her disciplinary inputs are better communicated and 'incepted' in the field, where the team can experience sensory evidence of them (INT, 19 min). Kim also hints that the site-readings of the designers is easier for her to appreciate, when shared in the field. Furthermore, the common fieldwork has the potential of actually merging disciplinary readings of a site (INT, 9-10 min). "In the field we often have very good conversations" (INT, 4-5 min) Kim describes how the common fieldwork provides sensitivity of the other team member and their ideas and even may produce 'common thoughts'. At SLA camp 2023 two groups aimed to learn more from the site through the act of 'listening'. One group was wondering about the succession of the site and the (multiple) actions and actors involved. They utilized signs placed on – and posing questions to – the entities at site (IDCR, p. 9-10). Another group equipped elements on site – soil, lake, rotten tree stem – with tubes and pipes for audio-enhancement, symbolizing intends of listening to what they might express (IDCR, p. 15-16).

- Tuning in / growing tentacles – means submerging into a situation – becoming local. In this process, the team may undress disciplinary restraints. Thus, this phase may awaken the teams' collective sensory apparatus and urge them to merge into one 'being' with many tentacles.

3.6 Take away

Kim shares how she has a habit of collecting a bouquet of flowers during fieldwork. This sample reminds her of the wealth already existing at the site. The sample is often placed at the office or given to a client as a token of this value (INT, 33-35 min). When sharing the bouquet habit, the mood of the interview changed, and both interviewer and interviewee seem emotionally affected. The sensuous gesture of the token seems to provide authentic representation of important actors on site, and the emotional bonds the design team built towards them. At the IDFW1 sample-taking also played a central role (Figure 2), and in the report from SLA camp 2023 there is also evidence of sample-taking and how the collection of matter and life from the site can generate both textural and emotional connection (IDCR, p. 5-6, 13-14, 19-20).

- Collecting flowers, taking samples, using aesthetic intuition may unfold an act of building care for the story of- and life on a site, which can awaken affect and enchantment.
- Taking away minor samples of flowers and matter from the site may comprise an act of care and compassion – moving from looking at site-inventory as matters of fact, towards engaging with them as matters of concern.



Figure 2: Photos from IDFW1. To the left: 'Take-away' and 'Processing' findings. To the right: 'Follow lead' in the woods. Source: (Holten-Andersen 2023).

3.7 Processing - conceptualizing

Kim remembers how a recent incident of IDF seemed to empower nature in the design project. After acknowledging the dynamics of natural processes at the site, these became the founding concept of the proposals. Kim describes how the collective site-visits afford "immediate inspiration." At the SLA camp 2023 and the interdisciplinary exercise in September a part of the fieldwork concluded with a processing-phase where the findings were conceptualized into design principles or a prototype (IDFW1). These sessions involved showing and telling what was found - discussing its value and role in the local act of life.

- Processing the findings and translating them into immediate design principles may empower nature in design. Such immediate processing can help translate findings into founding's for the further work.

3.8 Remembering

Numerous times through the interview, Kim speaks of how the common fieldwork provides contextual understanding and sensory experiences on site – and thus produces common memories of spaces and values. Kim emphasizes the power that lies in being able to revisit these memories and founding principles, later in the design process. Kim reflects how the initial fieldwork is an invitation to a much more co-creative design process: "*You may think that no one finds interest in your work, but they will, if you invite them to!"* (INT, 49-50 min). In addition, the brief from SLA camp 2023 mentions memory as a powerful purpose of IDF how aesthetic experiences of nature turn into memories and principles for future design.

- Building collective memories unites team members and serves as motivation to push for transformative change of urban sites.

4.0 PERFORMING AN 'AESTHETIC SENSE OF NATURE'

Founder and partner in SLA, Stig Lennart Andersson, has recently formulated a vision for 'the eco-centric city', extensively *liveable* for all species (Andersson 2023, 105). Andersson points out four values or performances that must be supported in the urban realm – the social, aesthetic, biological and rational (Andersson 2023, p. 102). These 'performances' resonates with the various fields of knowledge and expertise included in the design work at SLA (SLA 2024). Andersson calls for "expanded way of thinking that enables us to see the world from the other's eyes and not just from our own limited self-serving ego, knowledge and opinion" (Andersson 2023, p. 102). As both mean and goal of such an inclusive design process, Andersson promotes the 'aesthetic sense of nature'. By allowing ourselves to utilize this aesthetic sense, Andersson argue, we may evoke experiences and knowledges neither accessible through reasoning nor imagining. We find resonance for this argument in the phases of IDF distinguished above. We found that the aesthetic sense of nature resonates with emergent theories on how to turn our attention towards - and tune our actions to correspond with - the fragility and value of the Critical Zone and Deep Ecologies of sites (table 1). In the quest to bridge cultural and natural literacy, to move beyond scientific description or artistic inspiration, the 'aesthetic sense of nature' may very well perform as mediator, a common denominator – in which we allow ourselves to feel compassion for and close affiliation with site (nature) and team.

CONCLUSION

In this research, we put forward arguments for the relevance of Another Situated Design Approach, where the past decades great focus on co-design is stretched to entail involvement of the more-than-human actors of our environments – already present and operating at all sites. As step-one in such quest, we have suggested the launch of Interdisciplinary Fieldwork (IDF). In the empirical evidence, we found that the nature-based design office of SLA practises IDF, but not in a formalised manner. Digging into the somewhat limited data pool, we recognised that IDF carry the potential of contributing to disciplinary integration *and* provide depth to the understanding of the site investigated. Rather than providing plural or kaleidoscopic perspectives, IDF seemed to afford merging of disciplinary perspectives into conjoint appreciation of the site and bring forth useful insights for the design work to come. A superpower in bridging the disciplinary stances in nature-based-design may very well be the 'aesthetic sense of nature'. Going into the field together, seem to be an act of performing this sense, which may induce greater care and ecological awareness in projects. We arranged the findings in three stages and six phases of IDF, (1) Getting there; (2) Tuning in; (3) Follow lead; (4) Take away; (5) Processing; (6) Remembering, through reflection between data and theoretic inputs. These phases may draw the contours of a framework for IDF, to be further developed.

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ENDNOTES

[1] Beyond the excessive climate-gas emissions from these activities, continuous urban development claim land (Fertner, Smidt-Jensen, and Jørgensen 2023), disturb or destroy precious soils (Pickett and Cadenasso 2009), evict non-human-species, remove mature vegetation and increase pressure on- and pollution of blue-green infrastructures, particularly local waterscapes (Gómez-Baggethun and Barton 2013).

[2] E.g. Ian Mchargs Ecological Suitability Method (McHarg 1971) across Swanwicks LCA-method (Swanwick 2004) James Corners methodologies of mapping as motor (Corner 1999) and recently Hille Von Seggerns description of design as Raumgeschehen, which entails iterative 'nosing around' (Seggern 2019).

[3] As an interdisciplinary, but still natural science-based field, Earth Sciences aims to describe structure and functioning of the Earth as a complex, interrelated and adaptive system (Richardson et al. 2020). The very concept of investigation the 'environment' of a site may be contested in an Earth Science perspective, since "a living thing's milieu is other living things" (Aït-Touati, Arènes, and Grégoire 2019, 62). In recent years Earth Scientists has evolved operations of IDF establishing Critical Zone Observatories (Anderson, Bales, and Duffy 2008). Latour, Szerszynski and others have tapped into the concept of 'The Critical Zone', giving it a social-cultural aspect, (Latour 2016; Arènes, Latour, and Gaillardet 2018; Latour 2020).

[4] Christophe Girot has developed a site-exploration methodology he calls the 'Four Trace Concept'. Girot unfolds a framework consistent of four transitory phases: Landing, Grounding, Finding and Founding, to 'acquire understanding of a place' (Girot 2009, 60). The phases play out before, under and after visiting a site, the aim being to recognize a site, "beyond cultural and environmental amnesia" (Girot 2009, 59). Girot speaks of bridging two modes of thought – which we may identify as the approaches of natural-sciences vs sciences of culture and arts (Girot 2009, 66). His methodology, however, is primarily addressed to endow 'the designer' to go astray from a "systematic and quantitative approach" – and he does not further reflect on how to reconcile the disciplinary stances.

Cybermodeling into the Computational Unknown

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ABSTRACT: This Explorative Practice conducts digital architectural modeling through analogue means, a process known as 'cybermodeling.' This innovative practice was thoroughly examined in a recently completed Design Driven Doctoral Research (DDDR) and continues to be developed through workshops, lectures, demonstrations, and publications aimed at promoting its adoption in academia.

Cybermodeling, née hybrid analogue-digital modeling, utilizes simple microsensor technology to detect manual manipulations (bending, folding, etc.) and contextual information (gravity, light, distance, etc.). These sensors are embedded in the analogue model and connected to parametric code. This 'smart' analogue model serves as an interface for digital modeling, replacing traditional input devices like the mouse and keyboard.

The aim of cybermodeling is to find and support the material nature of computational objects. The importance of achieving or reaching a material quality in digital making is related to the ability of materials to respond and interact to their manipulations and to spatial forces. These reactions in media provide feedback in design making that influences design outcome. By directly linking digital models to real-time sensor data, cybermodeling creates 'live' digital design objects animated by the reactions of their digital material properties to spatial forces. Further, this approach teaches architectural design as an interaction with live media connected to dynamic systems (material, spatial, and environmental). Additionally, cybermodeling prioritizes our uniquely embodied intelligence by formatting digital design through physical making, thus accessible to sensory and intuitive understanding.

Cybermodeling is taught through three progressive tasks: building partial analogue and digital (parametric) models, calibrating sensor data, and then linking and adjusting analogue-digital modeling components to achieve an integrated cybermodeling experience. This Explorative Practice presentation offers an overview and live demonstration of the cybermodeling methodology, allowing participants to observe the setup and interact with the process firsthand.

KEYWORDS: cyber, hybrid, architectural modeling, microsensors, Firefly, Arduino

INTRODUCTION

This explorative practice, cybermodeling, seeks to find and support the material nature of computational objects. To this end, cybermodeling employs simple electronics and microsensor technology to connect computational architectural modeling directly to real-world spatial contexts of vector forces and atmospheric conditions. Following the modeling methods of Frei Otto and Antoni Gaudí—cybermodeling substitutes computational materials (Meshes, Surfaces, BREPs, etc.) for soap bubble solutions and weighted cables. By evoking behavioral responses inherent in computational materials as they react to site conditions (while also factoring geometry and spatial orientation), this methodology finds and emphasizes the material quality of the computational.

Currently in an initial stage of development, cybermodeling is carried out by embedding microsensors into the physical architectural modeling component then electronically linking this to a parametric component. Together analogue and digital components transfer sensor readings of manual manipulations and contextual data to inform a digital object (Figure 1 and 3). As a methodology, cybermodeling, a.k.a. hybrid analogue-digital modeling, seeks to integrate physical and digital making into one unified interface.

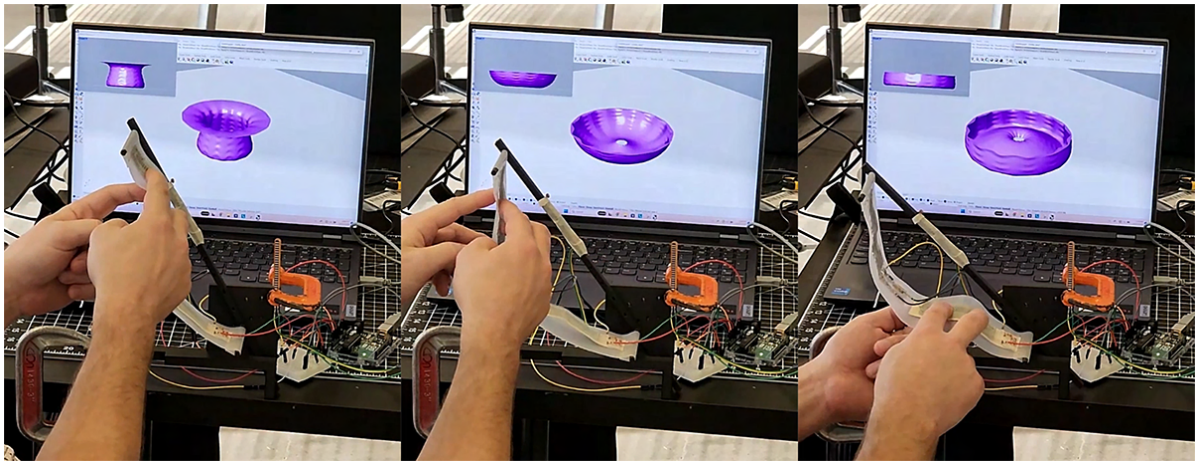


Figure 1: Analogue and digital components transfer manual manipulations and contextual data to digital object. Source: (Author 2023)

1.0 AIMS

1.1 Animated Computational Matter

The aim of this explorative practice is to emphasize the importance of materiality in architectural design process; a challenging task considering today's increasingly immaterial digital design culture. Cybermodeling, née hybrid analogue-digital modeling, stresses materiality in computational making by linking it to analogue making. Binding digital to analogue achieves two things: it reveals the existence of 'computational material properties'[1] and (re)connects digital modeling to context.

This explorative practice is authored by an architect whose 25-year career corresponds to the digitization of design practice. Such first-hand experience in both making modalities imparts awareness and appreciation of their difference. Specifically, in traditional, physical making, what is made is inherently and inescapably determined by material properties reacting in a spatial context *during* making.

In physical materials, the natural interaction between material and spatial properties is defined as *spatiomateriality*[1]. The spatio-material connection means that space and matter are connected at a molecular level. This connection and ensuing reactions animates media, giving it agency to respond. This is exhibited in the models of Otto and Gaudí which transfer spatial forces through material properties which in turn respond and react in form-finding.

This exploratory practice identifies the lack of spatiomateriality as a key problematic in contemporary computational design. Due in-part to the isolation of the design object separated from its spatial context. Isolating the design from context also renders computational materials neutral, unable to respond to context. Therefore one of the priorities of cybermodeling is to attach computational materials to context, making their neutrality impossible and redefining digital modeling as wrestling with a 'live' subject.

1.2 Cyber

In its development subsequent to doctoral research, hybrid analogue-digital modeling has been reframed as cybermodeling. The term flirts with notions of 'cyberspace' as coined by the sci-fi writer William Gibson, whereby

> …cyber…(was) generically and universally adopted…to evoke almost anything related to electronics and computers…a moniker for any technologically mediated alternative to physical space. (Carpo 2023, 25)

As electronically enhanced (micro- sensors and controllers) analogue models linked as interface to parametric making, cybermodeling connects and engages composite analogue and digital worlds.
Additionally and as unintended outcome, cybermodeling reveals a stark similarity between physical (biological) and computational (algorithmic) material behaviors. Thus 'cybermodeling' raises aspects of cybernetics emphasizing

> …the similarity between the binary operations of electronic computers and…living cells (which suggest) a deeper correspondence…warranting the parallel study of computation and (biological systems) (Carpo 2023, 25)

Contained here is the idea, carried over from the doctoral research, that both algorithmic and biological materials are ruled by their internal structures, or properties, which cybermodeling seeks to bridge. Already as a practice, cybermodeling delivers more than an artificial linking of analogue-digital modeling methodologies. The practice finds and connects the bonded spatiomaterial interactions underlying both worlds, their material agency determining what is and can be made.

1.3 Reverse-engineering digital fabrication

Making digital objects through analogue means. The novelty of cybermodeling is to reverse the flow of information from digital to physical that dominates contemporary digital making. The impetus for this radical action stems from first-hand experience. Engaging the media and modalities of both environments imparts an impression of a richness in sophistication in analogue over computational. Thus a main driver of this explorative practice has been to enrich computational with analogue making. But—the surprise found through linking the two modalities is the presence of

a rich 'materiality' lurking within computational media. This computational materiality, or computational material properties[2], is understood as internal structures of digital materials that direct their behavior and formal capacities. By activating computational material properties cybermodeling seeks to prioritize their direct engagement in digital making. Recognizing that microsensor smart technology and kinetic design modeling can access and attach computational objects to our haptic understanding and to context, this methodology reappropriates these technologies to create computational objects.

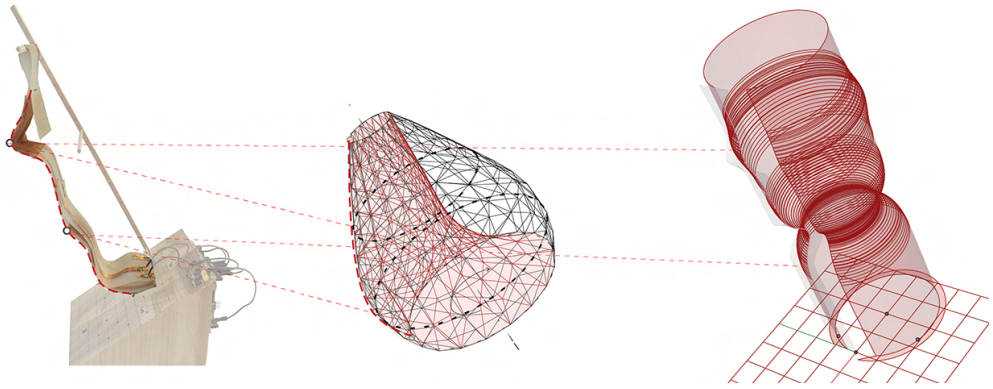


Figure 2: Workshop design problem, design a rubber vase sited on an incline. Source: (Author 2022)

2.0 METHODS

2.1 Workshop as methodology

Cybermodeling, originally a Design Driven Doctoral Research (DDDR) examining the impact of the analogue to digital shift in architectural modeling, is currently being further developed through workshops so that

> Findings (are) made accessible to others…communicated and contribut(ing) to the overarching discourse.' (Ludwig and Voight 2021, 228)

Workshops have been conducted with advanced digital design practitioners in conferences and universities. Thus, workshops act to both develop the methodology through the shared expertise of participants while encouraging adoption within the design community. The workshop discussed here took place at the ACADIA 2023 conference. Workshops cultivate accessibility through the availability of hobby micro-controllers and sensors (Arduinos) and freeware (Firefly), which translates sensor data into parametric modeling. The workshop design problem is simplified, the design of an inclined 'rubber' vase. The analogue model component is a rubber strip embedded with sensors to detect manual shaping. This rubber strip represents a section of the vase that is rotated in parametric modeling. Thus the cybermodel is a composite of a non-structural membrane (analogue rubber with computational B-Spline) subject to spatial forces like gravity (Figure 2). The vase serves as a simplified building envelope incorporating openings, patterns, and shapes influenced by contextual factors such as sound, humidity, and light. For instance, when sound is detected, a hole is created in the vase based on the sound intensity (Figure 3).

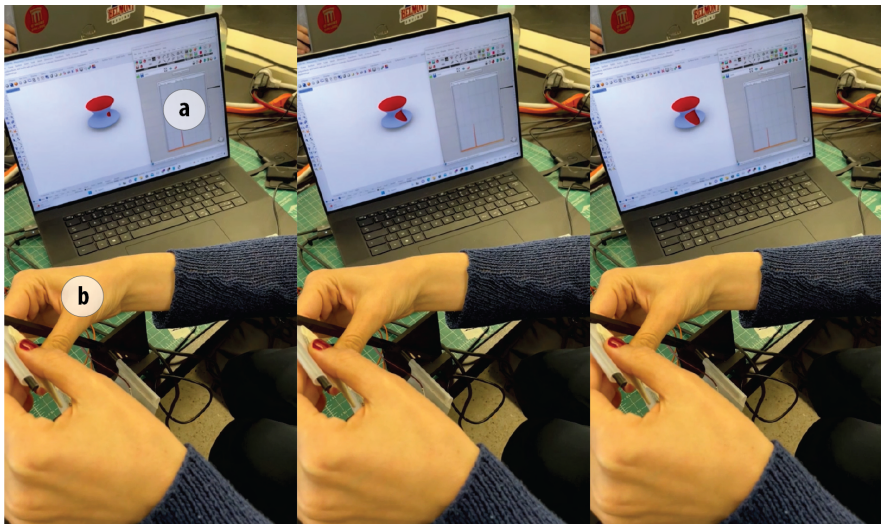


Figure 3: Vase designed through a. sound detection (levels depicted in graph) and b. manual shaping. Source: (Author 2023)

Cybermodeling as burgeoning methodology, lends a quality of improvisation to these workshops that encourages participants to share expertise. Workshops deliver an experience of digital making informed

> …through risk in the material, tools and techniques, (until this) workmanship is pushed to its limit and new knowledge can be generated. (Loh 2016,189)

The various platforms connected in the methodology (electronics, coding, physical and digital making) attract participants from diverse backgrounds and interdisciplinary expertise. Including a fine-grained differentiation among designers familiar with programmatic scripting, construction and fabrication, parametric modelling, or electronics. In-person workshops solicits group experts as temporal docents assisting and influencing the tasks and realisations. The ensuing workshop milieu has greatly aided the methodologies technological development (Figure 4).

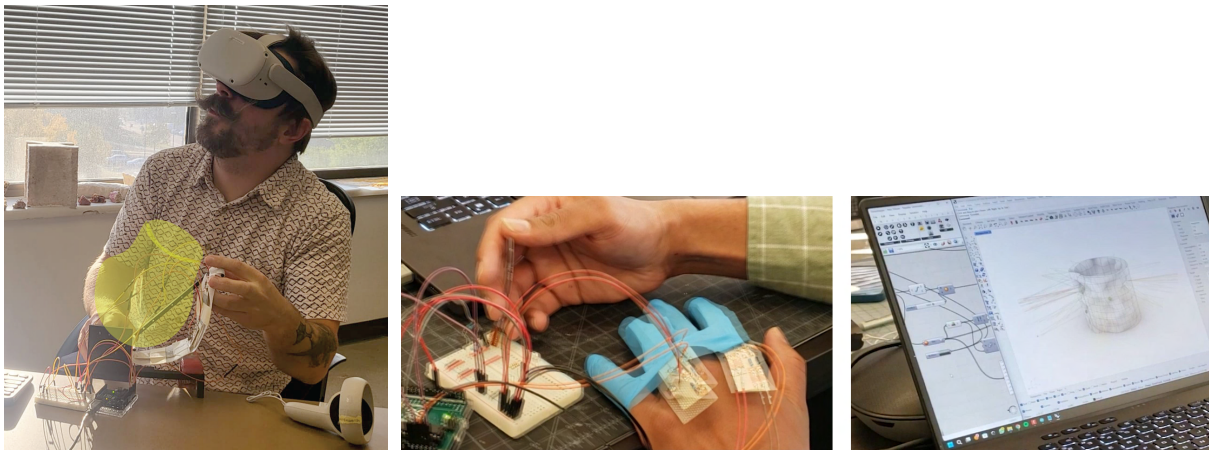


Figure 4: (left) participants added AR equipment and (right) D.I.Y. glove to the cybermodeling interface. Source: (Author 2023)

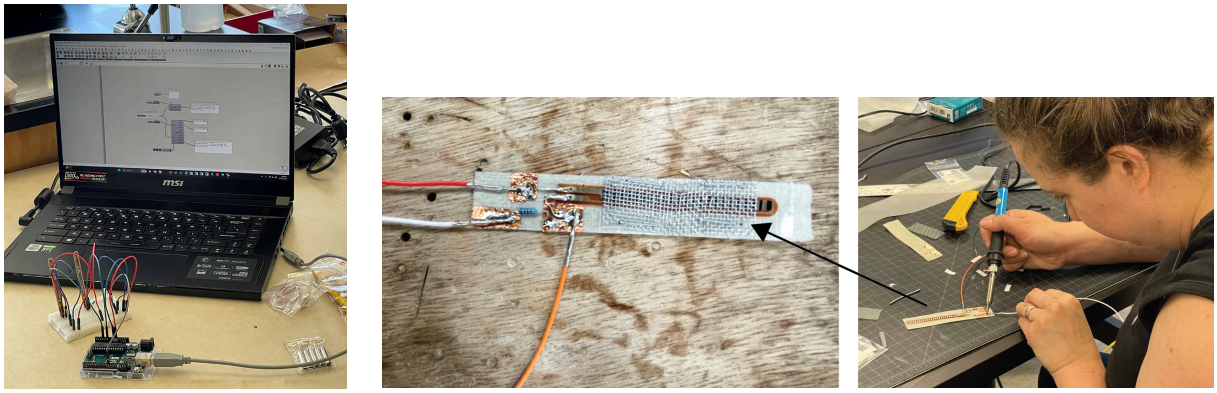


Figure 5: (left) microsensors interface to parametric modeling (center, right) building sensors into materials. Source: (Author 2023)

2.2 Practice as research

Focus on technological development and adoption in academic and professional practice directs the nature of this exploration from practice to research. Workshops are designed and deployed to test the methodology using the same design problem across multiples of events and participants. The workshops strive for regular and controlled learning through incremental lessons of building the cybermodeling interface: connecting and reading sensors in parametric modeling (Figure 5, left); building sensors into analogue model components (Figure 5, center and right); building parametric model components; and finally connecting analogue-digital components. A fourth 'step' runs continually and in parallel: tweaking and troubleshooting along each of these steps towards an integrated analogue-digital modeling engagement.

Thus workshops aim for:

> … universal application…enabling others to learn from the process of finding a solution in a specific case in order to be able to transfer and further develop this approach to other similar, but not identical, questions. (Ludwig and Voight 2021, 227)

Importantly, the workshop format is chosen to convey the tacit and heuristic knowledge found in modeling practice. Through this regular and measured method, individual projects find 'magical, artsy, intuitive' methods stemming from the background and character of the participant (Figure 4). While currently focused on technological development and adoption, the intention is to test the methodology with increasing levels of project parameters thus applicable to architectural design process and projects.

3.0 MODES OF OPERATION AND HUERUISTIC LEARNING

3.1 Learning workmanship

As heir to craftsmanship origins architectural practice conducts analogue modeling in what David Pye describes as the 'domain of quality'. Making in physical modeling requires care and attention to ensure stability of construction. However, there is a level beyond adequate, this is the domain of quality. In this domain, workmanship in making derives from contemplating a material enabled by the shear amount of time it takes to tool and shape it.

By intentionally binding digital to analogue making, cybermodeling seeks to induce this kind of retrospection-in-making that aligns the designers' actions to the material's logic. Simultaneously accessing the facility of computational making to translate data or input into formal design articulations such as sound detection used to create holes in the vases corresponding to intensity and proximity (Figure 3). Additionally, introducing electronics into these constructions adds to the level of care due to the low tolerance for error in creating and maintaining the flow of electrical current, (Figure 5, center and right).

The importance of attunement through workmanship of materials and tools, requiring skill and precision, is to attain a "…craft practice (wherein) the feedback (from the design object) is not just recursive but also generative...", i.e., the design object is not neutral but actively influences what is made. Further, as a design and modeling methodology, workmanship in cybermodeling is cultivated so that as "the practice evolves, the aesthetics and design co-evolve with this knowledge…over time (and)…over projects." (Loh 2016,199)

3.2 Learning risk

The design project examined in cybermodeling workshops initiates by instigating peril: sited on an incline with an assigned floppy and non-structural materiality. As a cybermodel the analogue-digital materiality is rubber and computational mesh respectively. These risk factors ensure that the resulting design must negotiate stability, thereby become a product of its spatial orientation and material nature. Material and spatial interplay is an essential trope of architectural design. Since the model calibrates its material and spatial condition, the architecture resulting fits site in a manner integral to its integrity.

In terms of design process making, cybermodeling seeks a level of craftsmanship defined by Pye as 'the workmanship of risk' in which "The essential idea is that the quality of the result is continually at risk during the process of making." (Pye 1968, 20) The strategy used in cybermodeling is to burden digital with analogue methods. Thereby adding risk in terms of sustaining electrical circuitry and aligning analogue-digital material behaviours. This delivers a slowed computational design process through preoccupation with spatio-material reactions across design media modalities.

3.3 Learning computational material properties through alignment

Computational materials routinely exhibit alien behaviors (such as infinite elasticity) that hinder our intuitive understanding. Cybermodeling requires bringing analogue-digital behaviors in alignment to create a unified modeling engagement. The alignment of computational to analogue material behaviors serves to bring computational matter into our shared experience of lived reality, allowing access to our intuitive reasoning and embodied channels of understanding[3]. The use of sensors to connect analogue to digital making is deliberately trying to open the channel of sensing in computational space. By running computational process through physical making, cybermodeling prioritizes our uniquely embodied intelligence. The methodology seeks to leverage the capacity of analogue modeling to include a greater percentage of human embodied intelligence, paired with brute force computing's ability to capture and model real-time dynamic variables of project site and material conditions. The experience of cybermodeling creates space for our 'superordinate programs' (Tooby, 2008) of experiential and intuitive intelligence; teaching digital designers to trust these instincts just as they would objective data.

4.0 INTENDED OUTCOMES

4.1 New materiality

Intended outcomes are to activate materiality as a partner in digital architectural design modeling. This is done by de-isolating the computational design object using sensor technology to attach it directly to site conditions. This has the effect of animating computational material natures responding to sensor data based on internal structures. Designers working with animated, 'live' models capable of factoring their spatial condition through material properties are faced with a dialogue, partnership, and negotiation with the subject of their investigations (Figure 6). The instant awareness and eventual respect of computational material natures connect digital making to a craftsmanship attitude. This entire enterprise directs digital architectural design away from hylomorphic neutrality toward the concept of New Materiality, that conceptualizes all making as engaging

> …an active matter endowed with its own tendencies and capacities, engaged in its own divergent, open-ended evolution, animated from within by immanent patters of being and becoming. (Delanda 2015, 16)

4.2 Unintended outcomes: spatiomateriality

Cybermodeling, initially an effort to increase the material nature of digital making, has, through

> …the techniques, tools and materials…developed within the workflow itself…an autopoietic system where tools are modified, adapted and invented. (Loh 2016,195)

unintentionally revealed the existence of computational material properties. Moreover, attaching computational materials to real-time environmental data and manual manipulation, reveals their quasi-sentient or 'live' capacity to respond. These findings led to the concept of spatiomateriality, identifying the true nature of physical materials as inescapably bonded to spatial contexts. The bonded spatio-material quality, necessary to animate design process media, us being pursued in this research as a quality inherent to computational making.

4.3 Other disciplines

Historically, architectural design has been driven by factors of site and material conditions as well as coeval technological advancements. The potential of cybermodeling is to develop digital design practice as formal computation factoring on-site orientation (cantilevered, suspended, etc.) relative to geometric configuration and material composition (analogue and digital). Such a practice could potentially optimize formal solutions (material

distribution, adding or subtracting mass, creating rigidity or flexibility etc.) based on specific site conditions. To the extent that these ‘architectural’ factors are relevant to other design processes, such as prosthetics or a novel from of telepresence making for remote collaborative working—remains to be seen.

5.0 EXPLORATIVE PRACTICE DESCRIPTION

5.1 Cybermodeling as conference tool

The goal of applying to this conference is to introduce cybermodeling to the EAAE/ARCC community, offering an experience of "Architecture into the Unknown" through novel computational making. This presentation aims to broaden the understanding of cybermodeling within the digital design community, particularly in academia, to influence the next generation of design practitioners. The cybermodeling presentation will provide an overview of its methodologies, development, goals, and challenges, inviting educators and students to engage and contribute to its evolution. A live demonstration will allow participants to try out the methodology, gaining familiarity with this new approach to computational making, which emphasizes the material nature of digital design. The presentation will also cover electronics, micro-sensor/processor data collection, and data mapping as tools for developing architectural design strategies by first animating digital design objects. Cybermodeling is an open platform that encourages participants to bring their unique expertise to the process. The workshop welcomes students, practitioners, and professors, aiming to integrate cybermodeling methodology into mainstream digital design practice.

CONCLUSION

Cybermodeling is explorative practice operating between theoretical concepts of the computational. The first is Kwinter’s description of complexity as

> implying the presence— within a given system—of a surplus of variables whose interactions cannot be correlated or predicated ahead of time with any degree of certainty. (Kwinter 2001, 21)

This statement seems to describe natural systems such as weather or biological processes, systems containing vast multitudes of interconnected and codependent variables which defy predictability.

On the other side of this conceptual spectrum is Frei Otto, who said of computerized making that

> The computer can only calculate what is already conceptually inside of it; you can only find what you look for in computers. (Songel, 2010, 38)

Therefore Otto describes the computational environment as extremely predictable. The goal of Cybermodeling research is to bring some of the (analogue) natural physical environment complexity, described by Kwinter, into the organized, predictable world of the computational, described by Otto.

Cybermodeling is an amalgamation of computational algorithmic matter, dynamic spatial contexts of vector forces and atmospheric conditions. Cybermodeling intentionally activates and accesses a computational material intelligence that, like analogue materials, contains agency based in its own divergent laws and capable of swaying design outcome. We invite the intrepid explorers of the ‘Architecture into the Unknown’ conference to join us in interfacing and querying the potentials of live, spatiomaterial computational media. We invite you to cyber-model,

> to make the electronic world work for us to reimpart the rich indeterminacy and magic of matter out of arid, cruel, and numericlized world of the reductionist mechanical and the disciplinary electronic... (Kwinter 2003, 91)

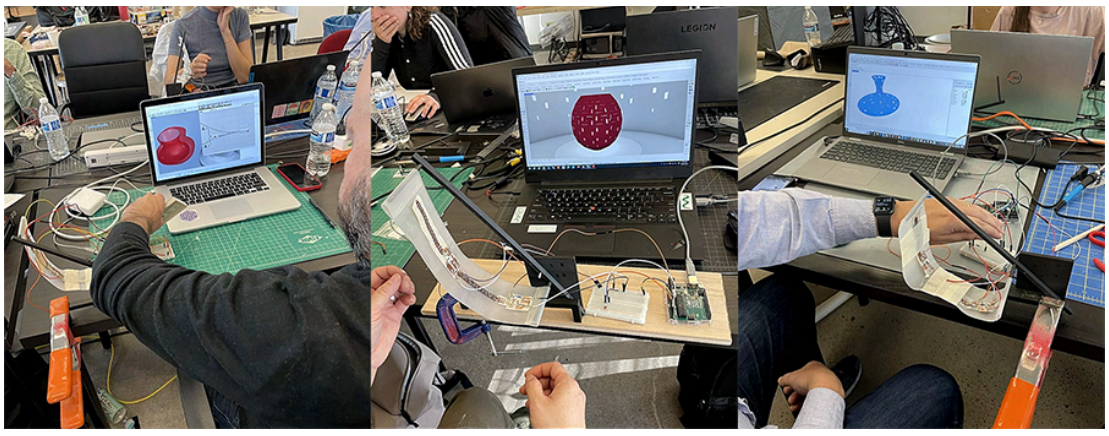


Figure 6: Variation in vase designed through cybermodeling readings of context. Source: (Author 2023)

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ENDNOTES

[1]The existence of computational material properties has been documented in other research, notably in Jahn, Morgan, and Roudavski. (2014).

[2] The concept of spatiomateriality was formulated in the author’s doctoral research. (Iverson-Radtke 2022).

[3]“Real reason is: mostly unconscious (98%); requires emotion; uses the ‘logic’ of frames, metaphors, and narratives; is physical (in brain circuitry); and varies considerably, as frames vary.” (Lakoff 2014, 72).

Artificial Intelligence-Assisted Thematic Analysis: A Contribution to Architectural Research

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ABSTRACT**:** Architectural research involves comprehensive analysis of diverse data, including user satisfaction data, interview excerpts, plans, and photographs. Analyzing such qualitative material is costly and time-consuming. While architectural programming firms often use qualitative data analysis software, many practitioners rely on informal methods. This article explores AI-assisted content analysis by comparing it with human-centered analysis in two case studies. Efficiency, accuracy, and replicability were evaluated as key criteria. Case Study 1 utilized open-ended responses from a survey of 356 school staff about school premises, informing design guideline development for public school renovations in Quebec, Canada. Case Study 2 analyzed 33 interviews with teleworking mothers involving architectural plans, dwelling photographs, and participant profiles aimed at enhancing home office environments. The human-centered analysis included manual transcript splitting and coding, alongside reviewing photographs and plans. Our findings show that AI-assisted analysis excels in efficiently disassembling and reassembling data, while having some shortcomings in compiling and interpreting data. It also demands considerable expertise in prompt formulation, which hinders accuracy and reliability. Human-centered analysis, although inefficient, requires data familiarity, knowledge of evidence, and research experience. All three are absent from the models' training. In conclusion, the potential of artificial intelligence to streamline qualitative analysis is discussed.

KEYWORDS: School renovation, POE, Thematic analysis, AI-Assisted Qualitative Analysis, ChatGPT-4.0®

INTRODUCTION

Qualitative content analysis in architecture, whether in academia or architectural practice, presents significant challenges in terms of resource allocation and costs despite the availability of specialized software packages. This form of analysis, applied to data of various kinds, from focus groups, unstructured interviews, or open-ended surveys, supplemented by various forms of imagery, is particularly valuable in architectural programming and post-occupancy evaluation. Such expertise is crucial for design projects tailored to meet user needs within specific geographical, cultural, and political contexts. While qualitative analysis software like NVivo exists, its adoption in architectural firms remains limited due to the required know-how and time constraints. Can artificial intelligence (AI) alleviate these challenges? Are AI-driven analyses efficient, accurate, and reliable? How do AI-generated interpretations compare with those derived from human judgment? This paper explores these questions through a comparative study of traditional human-driven content analysis and AI-assisted methods, evaluating ChatGPT's efficacy in processing text and images and aligning its categorizations with human-derived insights.

AI has been available for several years, and extensive literature is emerging to determine how AI tools like Large Languages Models[1] (LLM) and machine learning can be proficiently used in various disciplines (Aslam & Nisar 2023; Ayoub et al. 2023; Chubb 2023; Dergaa et al. 2023; Hitch 2024; Hyun Baek & Kim 2023; Lixandru 2024). Furthermore, the integration of LLM like ChatGPT-4.0® with image processing capabilities, e.g., DALL-E[2] in the case of ChatGPT-4.0®, is beginning to enhance qualitative analysis for professions heavily reliant on visual data, such as architecture. Epistemologically, qualitative analysis is prone to replicability issues since text coding is inherently influenced by cultural perspectives (Aiello & Sorde-Marti 2021; Pérez & Cannella 2013; Uri 2015). Similar concerns apply to ChatGPT's training, which is based on internet-available data, reflecting a Westernized worldview. Nonetheless, its development has advanced our understanding, mirroring insights into human cognitive processes (Waldrop 2024). For example, at the start of this project, we expected ChatGPT to operate like a black box, stable, and influenced only by software updates to the model. However, it turned out that AI-assisted analysis also has its own biases.

The limitations of AI usage raise questions about overlooking significant errors or failing to grasp important discoveries, as well as offering an allegedly replicable analysis. How efficient is its output? Is it truly replicable? How reliable and accurate is it for researchers, and what precautions are necessary? Premature reliance on AI may obscure essential analytical depths crucial for rigorous inquiry, prompting careful consideration both in architectural educational settings and professional practice.

This article stems from a workshop presented at the EAAE/ARCC Conference 2024 *Architecture into the unknown* in Aarhus, Denmark. Audience feedback highlighted key aspects of qualitative research with ChatGPT, aiding in the development of an evaluation framework based on its application in psychology, where accuracy and replicability emerge as primary concerns (Orrù et al. 2020). Among the comments from the workshop's audience that enriched our framework was the model's inherent versatility in assigned roles. For instance, it can prioritize elements in images or text or simulate the architect-client relationship in a classroom setting after being told, for

example, to "become a client for a residential project." These capabilities complicate assessing tool accuracy, as slight adjustments can disrupt the study or require restarting interactions, thereby diminishing efficiency. Therefore, we emphasize the complexity and potential pitfalls of nuances during prompt writing, which entails a steep learning curve and varies with the specific characteristics of each project. For this study, we concentrate on efficiency, accuracy, and replicability.

Efficiency is defined as requiring less energy and time than human analysis to perform the following tasks involved in qualitative thematic analysis (Braun & Clarke 2019): compilation, disassembly, reassembly, interpretation, and conclusion (Castleberry & Nolen 2018). Accuracy is assessed by the presence of errors or the confirmability of the analysis, which aims to establish that the researcher's interpretations and findings are clearly derived from the data, requiring the researcher to demonstrate how the conclusions and interpretations were arrived at as explained by (Nowell et al. 2017, 3), while replicability is defined as a measure of accuracy when repeating analyses on different types of data, influenced by inductive and deductive iterations within thematic analysis (Fereday & Muir-Cochrane 2006).

Case study 1: the first case study is drawn from Schola, a five-year action research program funded by the Quebec Ministry of Education (Canada), to develop a platform of expertise in school architecture supporting professionals involved in the renovation of public schools (Després et al. 2023). These buildings, built mostly between 1948 and 1973, have reached the end of the first architectural life cycle and require considerable investment. In the specific case of secondary schools, staff working in a sample of 75 school properties, randomly selected among the 391 buildings in the province of Quebec, were invited through their administration to take part in an online survey about their perceptions of each school's work environments: a total of 356 employees from 41 school properties completed the 140-item questionnaire. AI-assisted and human-driven content analyses were performed on the 25 open-ended questions present in the survey. In the human-centered one, responses were manually split into meaningful segments, assigned to one or more labels, and later grouped into thematic categories. In the AI analysis, the textual responses were submitted to the Chat Generative Pre-Trained Transformer (ChatGPT).

Case study 2: The second case study is part of a research project that examines the impact of housing on mental health during the COVID-19 pandemic. This qualitative study focuses on how housing conditions influenced the material adaptations of teleworking mothers during the pandemic. It investigates the interplay between housing conditions, daily routines, and telework setups during stay-at-home orders and progressive adaptations carried out by residents. Narrative accounts were gathered through 33 semi-structured Zoom interviews with teleworking mothers, supplemented by annotated architectural plans. AI-assisted discourse analysis using ChatGPT-4.0® was conducted on floor plans, dwelling pictures, participant profiles, and interview extracts for thorough architectural assessments and to uncover each group's material adaptations. The findings were compared to manual qualitative thematic analysis of assemblies using images and interviews. We employed codes obtained from live interview notes and a two-month reflection process.

The following results section presents the content of our human-driven analysis, followed by the ChatGPT-4.0® analysis for both case studies, and then moves on to a comparative discussion of the efficiency, accuracy, and replicability of these methods.

1.0 METHODOLOGY AND OUTPUT

1.1 Human-driven content analysis of cases 1 and 2

The human-driven content analysis was carried out in several stages, which were identical for both case studies, with the sole exception that in **Case Study 1**, with the aim of avoiding personal biases, inter-coder reliability checks were performed between two research assistants. In contrast, for **Case Study 2**, the analysis was performed in text files, not tables, and images were also sorted out and categorized by one single coder.

Firstly, the files were anonymized. Comments to open-ended questions were extracted from the original transcriptions and cleaned up for grammar and spelling. A careful reading of all responses to each question followed next for the coders (or coder in study 1) to acquire a good sense of the content. These comments were then transferred to an Excel spreadsheet in the case of the first study and to text files in the case of the second one and split up into meaningful segments. The coding labels were defined as the responses to each question were read, which requires to go back and forth to already analyzed segments when a new code needed to be added. These labels were then grouped according to thematic categories.

A closer look at respondents' open-ended comments in **Case Study 1** illustrates the coding process. For example, a question asked school staff about the class(es) they teach: "*To what extent is the furniture in your main workroom adapted to your needs?".* Their response options were *"very much," "fairly well," and "poorly adapted."* If respondents checked "poorly" or "fairly well', they were asked to explain their choice. Over one-third of all staff who identified a class as their main workspace provided an open-ended comment (83/233) for a total word count of 1246. The recurrent themes identified in 154 text segments are, by decreasing order of importance, lack of storage space (56), worn-out furniture (27), lack of comfort (18), unsuitable for use (14), inappropriate dimensions (13), lack of security (12), insufficient furniture (5), lack of space (5) and difficulty to move furniture around (4). The answer provided by a special needs teacher covers at once several of these categories, addressing the wear and tear of the furniture, its lack of ergonomic comfort, and the impossibility of securing his equipment:

> *My desk drawers do not open properly, and my filing cabinet does not lock. My chair is torn, and my*

> *working position is not ergonomic. I have no keyboard for my laptop, and my screen is low. The bookcase provided for storing equipment lacks sturdiness.*
>
> (Teacher, special education, ID 114339694070)

For **Case Study 2**, all participant comments and various data from a quantitative database on the participants were grouped into text files, while images were organized into folders for each participant. The images consisted of two types: architectural plans of the dwellings of each of the 33 interview participants, for which we had extensive quantitative data and photographs of the participants' teleworking environments. Manually cross-referencing these three types of information proved to be very onerous due to the material's complexity, involving constant back and forth between text files and folders with images. As a result, we tried different approaches, first by working on text and images separately and then creating assemblies of both text and images to familiarize ourselves with the data.

The information was then manually coded using categories derived from these various approaches and along combinations of housing flexibility and participant adaptability: 1. Low Housing Flexibility - Low Participant Adaptability, 2. Low Housing Flexibility - High Participant Adaptability, 3. High Housing Flexibility - Low Participant Adaptability, 4. High Housing Flexibility - High Participant Adaptability.

1.2 Artificial intelligence-assisted content analysis for cases 1 and 2

For the AI-assisted content analysis, ChatGPT-3.5 ® was first tested for both case studies. This free-to-use version requires that input text be of a maximum of 1024 words, that is, 4096 tokens. The language models used by ChatGPT process text in tokens rather than words, enabling them to consider the syntactic and semantic structure of a language. A token can be as short as a unique character or space or, else, a word. This maximum length includes the queries and the textual material to be analyzed as well. Since the 3.5 version does not accept tables, textual content had to be submitted in paragraph form, each line corresponding to one respondent. To overcome these limits, we turned to the paid version of ChatGPT-4.0®. Here, the maximum word count is 25,000 or 32,000 tokens, including prompts and answers. This version also allows for textual material to be input as tables that can be directly imported from a spreadsheet. In the case of the first study, the outputs can also be transposed into tables and exported back to a spreadsheet. Before proceeding with the analysis, participants' names and addresses were carefully removed from the answers to avoid uploading sensitive or identifying information to the ChatGPT database since it then became public domain.

Finding the correct prompt formulation was next, a task of paramount importance. It required several successive tests and adjustments before a sequence of prompts would generate the intended output. In addition to context, instructions, and content, the model requires what we preliminarily term category orientation. These inputs provide the model with a framework within the field and along the scientific literature, upon which deeper principles and research hypotheses are based. In the case of the first study, it was crucial to input sufficient context, incorporating five years of research experience in evaluating school environments in the province. Furthermore, prompts were systematically reviewed and refined using the model itself. In essence, the model can function both as a tool and as an expert assistant, helping with the sensitive task of formulating thorough instructions. In **Case Study 1**, for example, the initial query comprises three parts: first, a description of the study context; second, the specific survey question and answer; third, the information requested for the textual material to be analyzed, to which a fourth one was added when the 4.0 version was adopted, asking to format the results into a table (Figure 1). This last point was not included in **Case Study 2**, instead asking the model to evaluate images for each participant (including plans and dwelling pictures) as additional data.

2.0 RESULTS

In **Case Study 1**, once the query was launched along with the textual file, the Chatbot almost instantaneously generated the output, ranking themes from most to least frequently mentioned (Figure 2). In decreasing order of importance, they lack storage space (20), inadequate and old furniture (18), insufficient space (15), need for more modern equipment (12), ergonomics issues (8), and sharing and security concerns (5). Even though AI generated fewer categories, five instead of 8, they cover the same issues (Figure 2). The first two ones are about storage and furniture, the same as the human-coded ones. The two categories having to do with inappropriate dimensions and lack of space when codified manually were considered as one by the AI and labeled as "insufficient space."

Case Study 2 was interested in understanding the relationship between the materiality of the dwelling and the progressive adaptations of the participants, including cognitive, material-architectural, and time-use adaptations in the home. The thematic analysis was conducted using the model, but it was guided by previously established categories, some of which had been refined during the human-driven manual analysis. Specifically, we knew that participant's adaptations had been primarily of three types: material, cognitive and time use. We also had four typical profiles extracted through quantitative methods in a previous project, which roughly corresponded to the categories used during manual coding, combining housing flexibility and participant adaptability scores. The model was tasked with finding the themes describing participants' adaptations present in each text file and corroborating their content with the images provided in an iterative sequence. This triangulation between existing categories, information in text format with data on each participant, and images, i.e., floor plans and photographs of work areas within the dwellings, allowed for a complex thematic analysis yielding common and singular categories for adaptation strategies (Table 1).

Context of the query	These comments were collected via a survey conducted as part of a research project on the renovation of secondary schools. The aim is to analyze the qualitative responses to identify and quantify recurring themes.
Survey questions to be analyzed	The following question was asked to respondents: "Does the IT equipment you have at your disposal meet your pedagogical needs? Please justify your answer."
Content analysis prompts	For each category, the following information is required: 1. The title of the category, 2. The number of respondents mentioning it, 3. A summary in a few sentences describing the category, 4. An exemplary quotation supporting the summary, accompanied by the respondent's identification number and function. It is necessary to separate positive answers from negative ones."
Output format requested (in 4.0 version only)	Based on the results presented, can you create a table with four columns?

Figure 1: Prompts to ChatGPT for textual content analysis (translated in English but initially submitted in French).

1. **Category: Lack of Storage Space**
   - **Number of Respondents:** 20
   - **Summary:** Many respondents expressed a need for more storage space, including shelves for books and materials, drawers, and secure cabinets. The lack of adequate storage hampers organization and limits the materials teachers can keep in the classroom.
   - **Exemplary Quotation:** "Lack of space for a shelf for novels." - French Teacher, 114357361361
2. **Category: Inadequate and Old Furniture**
   - **Number of Respondents:** 18
   - **Summary:** Teachers are dealing with outdated, sometimes damaged, and non-ergonomic furniture. This includes old desks, chairs, and cabinets that are not suitable for modern teaching needs.
   - **Exemplary Quotation:** "The teacher's desk is a real antique: it lacks a drawer, the center drawer regularly jams, and you have to beware of splinters." - Social Sciences Teacher, 114343102421
3. **Category: Insufficient Space**
   - **Number of Respondents:** 15
   - **Summary:** Respondents highlighted the issue of insufficient space in classrooms to accommodate additional or more suitable furniture. This limitation affects the ability to create a dynamic and flexible learning environment.
   - **Exemplary Quotation:** "Lack of space." - French Teacher, 114354910122
4. **Category: Need for More Modern Equipment**
   - **Number of Respondents:** 12
   - **Summary:** Several teachers pointed out the need for more modern and adaptable furniture to meet current educational needs and support different teaching methods.
   - **Exemplary Quotation:** "Most date from 1974. Not adapted to today's orders and needs. Outdated and in poor condition." - French Teacher, 114351267561
5. **Category: Ergonomic Issues**
   - **Number of Respondents:** 8
   - **Summary:** Ergonomic issues with existing furniture, such as non-adjustable desks and uncomfortable chairs, were mentioned. These issues can lead to discomfort and hinder effective teaching.
   - **Exemplary Quotation:** "Desk non-adjustable, non-ergonomic at the height level." - Ethics and Religious Culture Teacher, 114349079520
6. **Category: Sharing and Security Concerns**
   - **Number of Respondents:** 5
   - **Summary:** Teachers who share classrooms or storage spaces expressed concerns about the lack of personal storage and security for their materials.
   - **Exemplary Quotation:** "Not much storage, especially when sharing." - English Teacher, 114354898283
7. **Positive Feedback**
   - **Number of Respondents:** 2
   - **Summary:** A small number of teachers expressed satisfaction or acceptance of the current situation, indicating that they manage with the available resources.
   - **Exemplary Quotation:** "It's okay." - Ethics and Religious Culture Teacher, 114348969072

Category	Summary	Exemplary Quotation	Number of Respondents
Lack of Storage Space	Need for more storage space including shelves for books and materials, drawers, and secure cabinets.	"Lack of space for a shelf for novels. - French Teacher, 114357361361"	20
Inadequate and Old Furniture	Dealing with outdated, sometimes damaged, and non-ergonomic furniture including old desks, chairs, and cabinets.	"The teacher's desk is a real antique: it lacks a drawer, the center drawer regularly jams, and you have to beware of splinters. - Social Sciences Teacher, 114343102421"	18
Insufficient Space	Issue of insufficient space in classrooms to accommodate additional or more suitable furniture.	"Lack of space. - French Teacher, 114354910122"	15
Need for More Modern Equipment	Teachers pointed out the need for more modern and adaptable furniture to meet current educational needs.	"Most date from 1974. Not adapted to today's orders and needs. Outdated and in poor condition. - French Teacher, 114351267561"	12
Ergonomic Issues	Ergonomic issues with existing furniture, leading to discomfort and hindering effective teaching.	"Desk non-adjustable, non-ergonomic at the height level. - Ethics and Religious Culture Teacher, 114349079520"	8
Sharing and Security Concerns	Teachers sharing classrooms or storage spaces expressed concerns about personal storage and security.	"Not much storage, especially when sharing. - English Teacher, 114354898283"	5
Positive Feedback	A small number of teachers expressed satisfaction or acceptance of the current situation.	"It's okay. - Ethics and Religious Culture Teacher, 114348969072"	2

Figure 2: Results of textual analysis of open-ended comments to a question about school furniture, with and without table query to ChatGPT-4.0® . Source: (ChatGPT, 2024)

Table 1: Output for adaptations across the four profiles (n=33). Source: (Authors, 2024)

Common Adaptations	**Profile 1:** Low Housing Flexibility - Low Participant Adaptability	**Profile 2:** High Housing Flexibility - Low Participant Adaptability	**Profile 3:** High Housing Flexibility - High Participant Adaptability	**Profile 4:** Low Housing Flexibility - High Participant Adaptability
Material	Creating Dedicated Workspaces. Adapting various areas into makeshift offices or workspaces. Acquiring Furniture and Equipment. Purchasing desks, ergonomic chairs, and digital devices for teleworking and online education. Spatial Reorganization. Reconfiguring living spaces to accommodate work, study, and leisure activities.			
Time	Adjusting Work Schedules. Aligning work hours with family needs or children's routines. Establishing Routines. Creating structured daily routines for work, childcare, and education. Balancing Work and Childcare. Actively participating in children's education and managing work-life balance.			
Cognitive	Reconceptualizing Home. Shifting the perception of home from a purely private space to a multifunctional environment. Altered Views on Work and Technology. Adjusting attitudes towards the role of work and the use of technology in daily life. Awareness of Spatial Needs. Recognizing the importance of personal space and the impact of living conditions on mental health.			

Unique adaptations	**Profile 1**	**Profile 2**	**Profile 3**	**Profile 4**
Material	High reliance on technology for space management use of communal spaces.	Conversion of home areas into multifunctional spaces, with emphasis on technological integration.	Creation of specific work and study areas, investment in noise-canceling devices.	Adapting smaller spaces for work, seeking external spaces for relaxation.
Time	Flexible scheduling to allocate individual time and space within limited living areas.	Creative engagement of children in educational activities, the establishment of professional appearance during remote work.	Delegation between partners for childcare, scheduling personal time for relaxation.	Establishing strict work hours and personal boundaries.
Cognitive	Heightened concern for personal privacy and space optimization due to confined living conditions.	Valuation of outdoor spaces for recreation, reflection on the dual roles of work and parenting.	Increased focus on physical and mental health management.	Recognition of the limitations of apartment living and desire for more open environments.

In a second step, the model was asked to provide the themes describing housing flexibility and participant adaptability for each participant and each of the four profiles, assigning points and providing a brief explanation to justify why some participants were enduring adaptation difficulties, and others were not. This procedure allowed us to understand the rationale behind the adaptation strategies that the model reported in its list of themes by category, effectively giving a sense of the models' accuracy/confirmability (Nowell et al. 2017). We were also able to see what the model was looking for when performing its analysis and how and with what precision. For example, when justifying why a group of participants had endured few challenges, the model writes on three main themes: "1. Emotional Resilience: Despite the obstacles, the participants remained positive and adaptive. Their ability to reorganize and set boundaries reflects an emotional strength and fortitude. 2. Flexibility: These participants exhibited a great deal of flexibility, whether it was moving homes, reorganizing spaces, or setting up new routines. 3. Seeking External Solutions: Whether it was moving to a new place, going outside more, or seeking therapy, they looked for solutions outside their immediate environment".

3.0 COMPARING THE ADVANTAGES AND DRAWBACKS

The results of applying human-driven analysis and AI-assisted analysis methods enabled us to weigh the advantages and disadvantages of each one and to take a critical look. The aim was to test AI for 1) *efficiency* by estimating the time and energy required to complete each type of analysis, 2) *accuracy* by comparing the grouping and labeling of comments with the ones derived from manual coding, and 3) *replicability* or the stability of AI analyses by having the same queries run multiple times or by different people and content (Table 2).

TABLE 2: Advantages and Limitations of Human-Driven and IA-Assisted Content Analyses. Source: (Authors, 2024)

	Human-driven analysis	AI-assisted analysis
Efficiency	– Extensive grammar and linguistic corrections – Coding task repetitive – Time consuming – High costs-benefits ratio	– Anonymization to remove sensitive data + Minimal grammar corrections + Fast execution + Simultaneous analysis of all data + Tabulation of analysis results + Low costs-benefit ratio
Accuracy	+ Adequate background knowledge + Knowledge of the database + Overall understanding of coding material – Omission of important elements	+ Correct vocabulary + Effective categorization – Simulated quotation – Invented persona – Difficulty in understanding colloquial expressions

Efficiency: The content analysis performed in **Case Study 1** by Schola's two research assistants required up to four hours of work per question, depending on the number of responses to be processed. The analysis grid was built up progressively as the responses were read, requiring coders to frequently either return to former text segments to add categories or carry out verifications of the results. Completing the task for the 25 questions took the equivalent of three 32-hour work weeks per employee. In contrast, the ChatGPT did the same job in a matter of seconds. While the Chatbot is capable of handling multiple queries simultaneously, slowdown or interruption in the workflow was experienced when doing so: submitting one query at a time for best results is recommended. Overall, AI-assisted content analysis offers unrivaled speed and the ability to process large volumes of data. In large-scale surveys, it facilitates the efficient synthesis of textual material and presents the results in an organized manner, namely analytical tables, increasing the capacity to use the findings in shorter timescales to support decision-making.

The difficulty of processing different types of information at once became evident when manually coding the data in **Case Study 2**. The sheer volume of text to be analyzed led us to set a limit on the coding work. This workforce limitation permitted us to analyze only 20% of the content for each participant by the end of one week of work. Despite this complexity, the manual coding process allowed us to identify criteria for synthesizing information that might not have emerged as easily if we had used the model. During the familiarization process, human-centered analysis can act as a hidden process where the researcher or coder unexpectedly discovers themes and categories reminiscent of scientific literature through inductive and deductive sequences, capturing "the qualitative richness of the phenomenon" (Fereday & Muir-Cochrane, 2006). In contrast, the model currently lacks sufficient memory and specialized knowledge. Nevertheless, once these classification criteria were established, identifying recurring themes proved to be an enormous task due to the 350 pages of text involved. The rest of the work was carried out using the model, and the manual work served to verify the accuracy of the thematic analysis.

Compiling, disassembling, reassembling, interpreting, and concluding are considered the five main tasks that account for the efficiency of thematic analysis. When comparing human-centered analysis with AI-assisted analysis, we observed that the model is particularly strong in disassembling and reassembling large amounts of information, but it is not recommended to prioritize its use for compiling, interpreting, and concluding. The process of compiling requires a certain order and direction and occurs in contact with the information but also with the experience and knowledge of the researcher. The same can be said for interpreting and concluding. For these tasks the model is better considered as an assistant than as a stand-alone tool. Its use does not replace familiarization with the data and iterative induction/deduction processes.

Accuracy: AI has not only the capacity to group segments of textual content around recurring themes, but it can also label the categories with explicit descriptive terms. This precise vocabulary is often lacking to architects, even more so students, while interpreting qualitative material. Even when compared to the labels chosen by coders, both trained in architecture and involved in the research project for over a year, the labels attributed by the Chatbot were often more accurate, the model having access to public web sources worldwide, including dictionaries. These AI-assigned labels could be used for further queries to ChatGPT to search for other knowledge types, such as evidence or architectural precedents. Furthermore, as evidenced by case study two, once researchers have identified the strategic axes for the types of categories or classifications they are seeking, the model can efficiently and accurately create labels and identify themes. For both case studies, during this labeling process, the Chatbot grouped certain segments of responses into themes that had slipped under the researchers' radar, raising useful hypotheses for design. The platform sometimes generated irrelevant groupings or else, categories that later had to be combined. In this last case, it was possible to ask the software to perform mergers, even though this was sometimes completed manually. Interpreting culture-specific linguistic expressions also proved to be sometimes difficult for ChatGPT (analogies, metaphors, colloquial expressions). Indeed, although the model works well in French, some expressions had to do with current events or popular language and were misinterpreted; corrections were then made manually.

One of ChatGPT's main limitations is highlighted by its response to one of **Case Study 1**'s requests to provide an exemplary quotation supporting the summary of each thematic category, along with the respondent's identification number and employment type. Manual checks in the original text were carried out for all proposed quotations. It appears that some of those, and even some respondents, had been invented based on the overall content of the target category. The Chatbot was thus quoting a "persona," a sort of robot portrait of respondents in the category. The veracity of all quotes was also checked by asking ChatGPT: "*Are all the quotes you provided in your previous answer true and taken from the data I provided in my question?*" The results were not always conclusive, but the Chatbot occasionally replied, "*I apologize for the previous confusion. The examples I have provided are not real but have been mentioned for illustrative purposes*". Finally, on complex data from multiple sources in **Case Study 2**, the model's output was verifiable but had significant limitations when it comes to counting cases.

Replicability: An important quality criterion for quantitative research is replicability. In qualitative research, it is, however hard to achieve. Indeed, any coding process is not exempt from bias, even if reliability checks between coders contribute to minimizing the risks. To check if AI would be more consistent than human judgment on the replicability of results, we ran the same queries multiple times. If the general themes remained, labels changed to some extent. In all cases, the qualifiers used to label the categories remain relevant, but the frequency of comments referring to them varied considerably. It may be sufficient to ask the Chatbot to distinguish between a "very high," "medium," or "very low" number of text segments associated with each thematic category to quantify data from a non-random sample. It is also important to understand that qualitative research proceeds from multiple sources, including floor plan analysis, on-site observation, or measurements.

By triangulating sources and by adding scientific evidence provided by the literature review, the subjective involvement of researchers is paired with that of many others. In this regard, results obtained by AI are generally considered to be more reliable, as the analysis is carried out without the potential biases inherent in human analysis, although small changes in the prompts can alter the output in unforeseen ways.

CONCLUSION

Our research evidences many advantages of AI-assisted content analysis. It significantly outperforms human-driven methods in terms of speed and efficiency, processing large volumes of data in seconds and facilitating faster decision-making for the analysis of large-scale surveys, specifically when thematic analysis outputs are not required to include verbatim or frequencies. AI demonstrates high accuracy in grouping and labeling textual content, often providing more precise terms than human coders, although it has limitations with colloquial and feeling expressions, as evidenced by **Case Study 1**. AI shows greater consistency in replicating results compared to human judgment. However, there are also significant disadvantages. One of these is the challenge of knowing when to utilize these tools, as premature adoption can hinder familiarity with the content and potentially overlook crucial information, as was evidenced in **Case Study 2**.

Specialized knowledge of the literature and the data at hand, cultural awareness, and the researcher's life experience are indispensable in providing direction and guidance for the analysis in ChatGPT-4.0®. These elements complement the understanding of the content being analyzed. Together, these three components form a triad that can be augmented by AI but not replaced by it. Neglecting the advantages of human interpretation and culture would be a serious mistake, likely thwarting numerous potential discoveries in the social sciences. As AI tools continue to evolve, they promise to transform architectural research and design by enhancing efficiency, accuracy, and replicability and above all, let humans overcome memory limitations while complementing the strengths of human-centered analysis. Researchers need to understand the limitations and non-linear nature of these tools. Like in manual coding, expert knowledge is still crucial for uncovering key ideas, ensuring humans remain integral to the field's advancement.

Several insights from the workshop's participants focused on the original instructions given before starting the analysis in ChatGPT. For instance, participants noted the ability to instruct the model to take the perspective of a client evaluating a project or to adopt the role of a housing ministry critic before the prompt was inputted. These perspectives mirrored the nuanced directions we gave while creating prompts. They were perhaps the most intriguing aspect of using the tool due to the important variations in replicability from such changes, soliciting considerable sensibility when choosing references or providing examples and finesse in the wording of prompts.

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ENDNOTES

[1] A large language model is an AI system designed to understand and generate human language using vast amounts of text data and neural networks.

[2] DALL-E within ChatGPT-4 is an integration of a visual language model. It was developed by OpenAI to generate images from textual descriptions, although it can also perform the opposite task, analyzing images and describing their content.

PAPERS

ETHICS AND SOCIAL RESPONSIBILITY

Restorative vs. Pathogenic Public Spaces: Investigating the Impact of Urban Green-Space Parks in Rapidly Growing Mid-Sized Cities

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ABSTRACT: Urban green spaces play a critical role in shaping mental health, offering environments that can either restore well-being or exacerbate stress. However, access to these restorative benefits often reflects deeper socio-economic patterns, raising questions about equity and inclusion. This study investigates how visitor perceptions of urban parks—gathered through Google reviews—differ between neighborhoods with varying degrees of gentrification. Examining this data alongside the socio-economic trajectories of neighborhoods in mid-sized cities like Greenville, Spartanburg, and Charlotte aims to inform urban planning and policy-making strategies that prioritize equitable access to restorative green spaces, ultimately ensuring that parks benefit all community members.

The stakes of this inquiry are significant. As cities grow and invest in public green spaces, disparities in access and perceptions of safety, usability, and comfort can emerge and perpetuate social inequities. This study situates itself at the intersection of urban design, public health, and social justice, asking: How do perceptions of parks as restorative or pathogenic align with neighborhood socioeconomic profiles, particularly in areas experiencing gentrification compared to historically marginalized neighborhoods?

By analyzing user-generated reviews, this paper uncovers recurring themes related to greenery, safety, accessibility, and community-oriented design. These findings are then juxtaposed with neighborhood-level data to reveal patterns of preference. Readers will learn how urban greening efforts may unintentionally contribute to social stratification and strategies for designing parks that prioritize inclusivity and shared well-being. Ultimately, this research highlights the need to reimagine green spaces as equitable resources, ensuring their benefits are accessible to all, regardless of socioeconomic status or neighborhood context.

KEYWORDS: Green-Space, Mental Health, Gentrification, Urban, Parks

INTRODUCTION

Urban green spaces have long been lauded as essential to the mental well-being of urban residents, offering opportunities for relaxation, social interaction, and connection to nature (Nutsford et al., 2013). Yet, the benefits of these spaces are not equally distributed (Engelberg et al. 2016). As mid-sized cities across the United States grapple with rapid growth, urban parks become contested spaces where questions of access, equity, and usability emerge. This paper delves into these questions through Google reviews by analyzing visitor perceptions of parks in mid-sized cities in the southeastern United States (Greenville, Spartanburg, and Charlotte), offering a window into how restorative and pathogenic qualities are experienced across neighborhoods with different socioeconomic profiles. A case-study approach allows a deeper exploration of the relationships between visitor experiences, neighborhood characteristics, and socioeconomic shifts, particularly regarding gentrification processes. Urban parks in these cities thus serve as distinct yet interconnected cases to better understand how the benefits of urban greening initiatives may differ by neighborhood.

This study focuses on the relationship between neighborhood gentrification and the perceived quality of green spaces. Parks in areas undergoing gentrification often receive high praise for their safety, aesthetic appeal, and maintenance, contributing to their restorative potential. In contrast, parks in historically marginalized or underfunded neighborhoods are frequently criticized for lacking upkeep, safety concerns, and insufficient amenities, fostering a sense of exclusion and discomfort (Anguelovski et al. 2018). These disparities raise critical questions about who perceives neighborhood green parks as comfortable, safe, and convenient.

The paper is organized into several key sections. First, the literature review provides a theoretical framework, exploring restorative environments, social equity, and green gentrification concepts. Drawing from the work of scholars such as Isabelle Anguelovski and Alessandro Rigolon, this section establishes the dual potential of urban parks as spaces of healing and harm. The methodology section outlines the study's comparative case study approach, detailing how mixed data were drawn from Google reviews, master planning documents, and historical records. These methods allowed for an in-depth analysis of user perceptions and their alignment with neighborhood characteristics. The results and discussion sections reveal a nuanced picture of urban park experiences. Across the five parks studied, themes such as the role of greenery, perceived safety, accessibility, and community-oriented

design emerge as significant factors influencing visitor satisfaction–and yet, contrary to our hypothesis, reviews were proportionally good across all parks. Still, important patterns emerged when paired with socio-economic indicators. While parks in gentrified neighborhoods were lauded for their thoughtful design and upkeep, they also sparked concerns about overcrowding and exclusivity.

Meanwhile, parks in non-gentrified areas were more likely to be described as poorly maintained and unsafe, reflecting broader patterns of neglect. The discussion examines how urban parks can simultaneously foster inclusion and exclusion, depending on their design, location, and the communities they serve. While not a central conclusion of this study, the concept of green gentrification is highlighted as an area for future exploration. Ultimately, this research underscores the importance of viewing urban parks as physical spaces that mirror social and economic realities. By illuminating the disparities in how these spaces are experienced, the study invites readers to rethink the role of green spaces in fostering mental health and social equity.

1.0 LITERATURE REVIEW

Gentrification is a complex socio-economic process characterized by transforming urban neighborhoods through the influx of higher-income residents. This transition frequently leads to the displacement of long-standing, lower-income communities, thereby altering the demographic landscape of these areas. One significant factor in this dynamic is the development or enhancement of urban parks, which, despite their numerous benefits, can unintentionally catalyze gentrification known as green gentrification (Anguelovski et al. 2022; Oscilowicz et al. 2022; Cole et al. 2017; Lewartowska et al. 2024).

Wolch, Byrne, and Newell (2014) argue that park planning decisions are rarely neutral; instead, they are shaped by a complex mix of political, economic, and social interests. While the benefits of urban green spaces are well-documented, their accessibility and qualitative characteristics are vital for maximizing their restorative potential, which is heavily influenced by socioeconomic factors, urban policies, and community engagement. Furthermore, research regularly connects access to green space with enhanced mental well-being but emphasizes challenges related to social equity and the risk of worsening socioeconomic disparities (Larson, Jennings, and Cloutier 2016). Planners have noted the lack of clear definitions and goals around green equity, inclusion, and justice, which hinders the effective implementation of equitable green planning within municipal climate action and sustainability efforts (Connolly, Anguelovski, and Oscilowicz 2023).

Beyond gentrification complexities, the design of urban parks plays a crucial role in influencing psychological and social well-being. The Attention Restoration Theory (ART) suggests that access to green spaces can alleviate stress and cognitive fatigue, improving mental health outcomes (Herzog, Maguire, and Nebel 2003). In addition to psychological benefits, green environments have been known to improve social interaction and reduce people's sense of loneliness (U.S. Department 2021; Pasanen et al. 2023). However, the effectiveness of parks in yielding these benefits depends on design elements such as vegetation or greenery, tree canopy coverage, seating availability, and maintenance quality (Klemm et al. 2017).

Moreover, neglect, poor maintenance, and safety concerns can significantly diminish the benefits of green spaces. Wang'ombe (2024) points out that inadequate infrastructure and safety issues can detract from the positive impacts expected from urban green spaces, contributing to higher crime rates and a growing sense of insecurity, particularly in underfunded areas. Further studies conducted by Jelks, Jennings, and Rigolon (2021) indicate that while urban greening seeks inclusivity, it can paradoxically lead to the displacement of low-income residents, undermining social cohesion and equitable access to park benefits.

2.0 METHODOLOGY

This study employs a mixed-methods comparative case study design. By integrating quantitative assessments of environmental psychology indicators with qualitative analyses of community perceptions, the research aims to elucidate how restorative and pathogenic elements of park design in a gentrified area Focusing on mid-sized cities experiencing rapid growth—Greenville and Spartanburg in South Carolina and Charlotte in North Carolina—the study will explore how history and growth trajectories shape perceptions and usage of these public spaces.

Data was collected using secondary sources, primarily focusing on extracting and analyzing Google park reviews, examining master planning documents, and reviewing historical data for each park. We collected all Google park reviews until December 14, 2024, with a total of n=30,979 reviews on a Likert scale and n=13,033 reviews, including written perceptions. Data was also extracted from Google using Outscapper.

2.1 Google review analysis

The analysis followed a multi-step process to examine Google reviews in relation to gentrification and economic class. First, the dataset was cleaned by removing duplicate entries, irrelevant content, and extraneous elements such as HTML tags. The reviews were then standardized for consistency, and a frequency analysis of key terms was conducted to identify dominant themes. Topic modeling, specifically Latent Dirichlet Allocation (LDA), was employed to uncover latent thematic structures, followed by a qualitative interpretation of sampled reviews within each topic. Sentiment analysis classified reviews as positive, negative, or neutral, with further categorization into five-star rating groups to extract major thematic narratives. Finally, qualitative coding was used to assess key environmental indicators—natural light, noise levels, greenery, and perceived safety—to evaluate their influence on

visitor perceptions. ChatGPT was employed as a computational tool to assist with data processing, text analysis, and thematic categorization.

2.2 Master planning documents and historical data analysis

Master planning documents and historical records were reviewed to understand the design intentions, development timelines, and socio-economic factors influencing each park's evolution. These documents provided insights into how planned features align with user experiences reported in online reviews.

A comparative analysis was conducted to juxtapose insights derived from user reviews with findings from master planning documents. The inductive approach allowed emerging themes to shape the analysis, condensing broad initial observations into focused conclusions.

3.0 RESULTS

The results were analyzed to compare user perceptions with the documented design intentions, revealing gaps and successes in park planning. Key observations were categorized to understand how design elements contribute to restorative or pathogenic experiences. We define restorative experiences as positive perceptions of green spaces, such as the accessibility of the park's features, a safe environment, and kid-friendly elements. Conversely, pathogenic experiences refer to perceptions that highlight the negative aspects of the park, including litter, overcrowding, and a lack of parking. The iterative nature of the study allowed for a dynamic interpretation of the data, refining insights over multiple analysis cycles.

We conceptualize gentrification as changes in the urban design structure of historically lower-income areas that impact the region's economic trends. This often results in the displacement of previous residents and the influx of new residents who meet the new economic demand. We utilized urban design plans and historical data to interpret gentrification in the park areas, noting inconsistencies in its measurement. Features such as added sidewalks, commercial businesses, water features, and increased funding for new amenities raised economic demand in these areas, attracting individuals from a higher income bracket.

While we anticipated higher restorative perceptions in parks within gentrified areas, our results showed similar pathogenic and regenerative perceptions across all parks. This suggests that perceptions of park spaces were consistent regardless of gentrification status, supporting a null hypothesis.

3.1 Park review findings

Most reviews for each of the five parks were considered “good,” with an average rating of 86.11%. Among the “neutral” reviews, the average rating among all five parks was 11.50%. In addition, reviews considered “bad” had the lowest percentage, with an average rating of 2.39% (Table 1). Across all locations, Falls Park in Greenville, SC, had the highest written reviews (9,996), while Latta Park had the lowest (420).

After analyzing the park reviews, five main themes, including three sub-themes, emerged (Table 2). The results of this study demonstrate both regenerative and pathogenic feedback through park reviews categorized into five main themes: the role of greenery, perceived safety, accessibility and connectivity, community-oriented design, and overcrowding as a barrier. Three sub-themes emerged: balancing open spaces and comfort, maintaining and perceived restorativeness, and social interaction and family-friendliness. For each main theme, including the associated sub-theme, three examples were highlighted from the overall park review to represent the characteristics of the conceptualized themes.

Table 1. The authors analyzed perceived gentrification based on an archival review of city planning maps obtained via direct contact and county-level population statistics from the U.S. Census Bureau data to estimate 2024. The authors identified the number of acres for each park through individual park webpages. All reviews for each park were collected via Google, through December 14, 2024, when the authors extracted data, including any review dated before extraction. Source: (Google, 2024)

Park Name	Park Location	# of Total Reviews	# of Total Written Reviews	# of “Good” Reviews	# of “Bad” Reviews	# of “Neutral Reviews	Perceived Gentrification Area	# of Acres
		N	*N*	*n(%)*	*n(%)*	*n(%)*	*Yes/No (Y/N)*	*N*
Latta Park	Charlotte, NC	863	420	357 (85.0%)	21 (5.0%)	42 (10%)	N	31
Freedom Park	Charlotte, NC	7,629	1,000	859 (85.9%)	16 (1.6%)	125 (12.5%)	Partially	98
Cleveland Park	Spartanburg, SC	2,235	1,035	903 (85.0%)	26 (2.0%)	106 (13.0%)	N	578
Falls Park	Greenville, SC	19,136	9,996	8,565 (85.7%)	31 (0.3%)	1,400 (14.0%)	Y	26
Unity Park	Greenville, SC	1,116	582	519 (89.0%)	18 (3.0%)	45 (8.0%)	Y	60

Table 2. Conceptualized Themes among Key Findings. Source: (Google 2024)

Theme *Sub-Themes*	Examples from Park Reviews
The Role of Greenery	Frequent mentions of the park's "trees" and "scenic beauty" indicate that natural elements are crucial to visitor satisfaction. -*Freedom Park (Charlotte, NC)*
Balancing Open Spaces and Comfort	Some feedback highlights a lack of sufficient shade in key recreational areas, impacting comfort. -*Unity Park (Greenville, SC)*
Perceived Safety	Positive reviews describe the park as "safe and family-friendly," but lower-rated reviews highlight concerns about "poorly lit areas" leading to discomfort. -*Latta Park (Charlotte, NC)*
Maintenance and Perceived Restorativeness	Some negative reviews mention "litter" and "overcrowding" issues, impacting overall perception. -*Unity Park (Greenville, SC)*
Accessibility and Connectivity	The park is praised for its "well-connected" trails and pedestrian-friendly design but faces occasional issues with crowded pathways. -*Falls Park (Greenville, SC)* Comments indicate that some entrances lack proper accessibility features for strollers and individuals with mobility issues. -*Latta Park (Charlotte, NC)*
Community-Oriented Design *Social Interaction and Family-Friendliness*	Visitors praise its open spaces that host local events and social gatherings. -*Cleveland Park (Spartanburg, SC)* Reviewers frequently mention "great for kids," highlighting the playgrounds and splash areas as key attractions for families. -*Unity Park (Greenville, SC)*
Overcrowding as a Barrier	Some reviews mention that "weekend crowds" make it difficult to find quiet spots. -*Freedom Park (Charlotte, NC)* Reports of "overcrowding in playgrounds" suggest the need for better spatial planning. -*Unity Park (Greenville, SC)*

4.0 DISCUSSION

4.1. Initial hypothesis and correlation with findings

This study examined visitor perceptions of environmental features (such as greenery, natural light, noise levels, and perceived safety) and how amenities shape overall satisfaction ratings across city parks with varying levels of gentrification. We hypothesized that areas depicted as gentrified through changes in urban planning designs would exhibit more restorative perceptions than areas that appeared non-gentrified, reporting pathogenic qualities. Contrary to our hypothesis, the reviews did not indicate a substantial divergence in public perceptions. Both gentrified and non-gentrified parks received similar proportions of positive and negative ratings, suggesting that visitor satisfaction was not shaped by potential gentrification status. Our findings highlight the complexity of measuring gentrification's impact through public perception alone.

4.2. Interpretation of findings

Collectively, findings from the parks' Google reviews (Table 2) emphasize the complexity of designing urban parks that cater to diverse needs while addressing challenges such as safety, accessibility, and overcrowding. By integrating greenery, enhancing safety features, improving accessibility, fostering community engagement, and mitigating overcrowding, urban parks can better realize their potential as restorative and inclusive public spaces. Although the analysis revealed a predominantly positive visitor experience, the underlying factors influencing these perceptions are opaque. Specifically, the review data did not directly capture respondents' positionality—particularly their socio-economic background and relationship to the neighborhood. Given this gap, further investigation into neighborhood changes at a higher level of fidelity becomes essential. Indeed, evidence of urban transformations observed in these parks suggests potential impacts of gentrification, which could alter park demographics and influence user experiences. Nonetheless, inconsistent definitions and measurements of gentrification complicate efforts to link demographic shifts to review authorship or thematic trends within park evaluations.

4.2.1. Green spaces generally receive positive reviews

Urban parks play a multifaceted role in shaping the experiences and well-being of their visitors (Jang et al. 2024). A central aspect of this is the presence of greenery, which consistently emerges as a defining feature in user feedback. Visitors frequently describe parks as "lush," "scenic beauty," and "green," underscoring the restorative potential of natural landscapes (Table 2). While we hypothesized "gentrified" parks to have more positive feedback, enthusiastic perceptions of the parks' greenery were consistent among each park area. However, the absence of adequate shading in some parks during warmer months is a common point of critique, particularly for visitors seeking comfort during their time outdoors.

Analysis of Google Reviews reveals a predominant focus on environmental attributes, such as greenery, cleanliness, and recreational facilities, leading to an overwhelmingly positive characterization of parks. Users

frequently praise these features, as elements like fresh air and spaces for exercise and play naturally garner favorable reviews regardless of broader socio-economic changes. However, reviews rarely acknowledge demographic shifts, rising costs, or changes in the social fabric that may influence park accessibility and use. Notably absent are perspectives from displaced residents or individuals who no longer feel welcome in these spaces. As a result, online reviews primarily reflect the experiences of current users, reinforcing a narrative that overlooks the social dynamics of neighborhood change and obscuring potential concerns about accessibility, exclusion, and displacement.

Perceived safety is a critical factor influencing how visitors engage with urban parks. Research indicates that individuals who perceive parks as safe are significantly more likely to visit and utilize these spaces (Lapham et al. 2016). Positive reviews highlight well-lit, high-traffic areas as safe and inviting, fostering a sense of security that encourages greater usage. Parks with clean, well-maintained amenities tend to elicit favorable responses, with visitors associating these features with a feeling of order and care. On the other hand, poorly lit or infrequently trafficked areas evoke discomfort and discourage use, particularly in the evening. Issues such as litter and inadequate maintenance detract from these spaces' visual appeal and amplify feelings of neglect and insecurity. These findings highlight the need for regular maintenance and thoughtful design strategies prioritizing visibility and cleanliness to enhance safety.

Despite the positive impacts of community-oriented spaces, overcrowding emerges as a recurring concern in user reviews, aligning with findings from other studies that identify overcrowding as a significant factor negatively influencing visitor experiences and potentially diminishing the restorative benefits parks offer (Aydemir et al. 2024). During peak times, congestion can hinder visitors' ability to enjoy the park, reducing the availability of quiet or personal spaces. Overcrowding in specific areas, such as playgrounds, also disproportionately affects children, limiting their access to essential recreational opportunities. This feedback points to the need for thoughtful spatial planning that accommodates both high usage and a variety of activities, ensuring that parks remain functional and enjoyable for all demographics.

4.2.2. Displaced voices are absent in reviews

In the context of displaced communities, capturing user perceptions presents a significant challenge, as online review platforms such as Google Reviews primarily reflect the experiences of current park users. Individuals most affected by neighborhood change—long-term residents displaced due to rising costs or demographic shifts—are often absent from these platforms, resulting in a gap in the dataset. This absence limits the ability to evaluate whether gentrification has rendered parks more exclusive or less welcoming to former residents, ultimately constraining assessments of how urban change influences access to and perceptions of public space. These findings underscore the need for participatory design approaches that actively engage current and former residents to ensure that public spaces remain inclusive and responsive to the broader community's needs.

Analysis of Google Reviews revealed recurring themes related to accessibility, connectivity, and the social function of urban parks. Reviews frequently highlighted the value of well-connected trails and pedestrian-friendly pathways, which were praised for enhancing mobility and creating a seamless visitor experience. However, accessibility challenges emerged as a notable concern, with reviewers citing insufficient parking and inadequate infrastructure for mobility devices and strollers. These barriers disproportionately affect families with young children and individuals with disabilities, indicating gaps in inclusivity that limit equitable park access.

The social dimension of parks also featured prominently in visitor feedback, particularly regarding the role of community-oriented design. Reviews consistently emphasized the appeal of parks that support social interaction through events, multi-generational gathering spaces, and recreational amenities. Features such as playgrounds, splash pads, and picnic areas were frequently praised for fostering community and belonging. These findings underscore the importance of designing parks that reflect the needs and aspirations of their communities, reinforcing the role of public spaces in strengthening social ties and collective identity.

4.3. Limitations of user-generated reviews in assessing gentrification and displacement

Gentrification is a complex and multifaceted process, making it difficult to define and measure consistently across different urban contexts. Although various institutions, such as Fannie Mae and the University of California's Urban Displacement Project, have developed novel mapping tools using Adjusted Median Income (AMI) to track gentrification trends, the methodology behind these calculations often lacks transparency. The U.S. Census Bureau provides publicly available income data that can be analyzed over time. However, the difficulty in determining the proportion of individuals above or below income thresholds limits its applicability at the scale of individual parks. Furthermore, demographic shifts alone fail to capture these spaces' social and cultural transformations, complicating efforts to establish clear metrics for gentrification.

These measurement challenges necessitated an alternative approach in our study. Relying on urban planning indicators, we categorized parks as "gentrified" or "non-gentrified" based on new amenities and infrastructure improvements. We also incorporated historical articles to contextualize contemporary developments and strengthen our analysis. However, the lack of standardized methodologies for assessing gentrification underscores the need for clearer guidelines and frameworks to evaluate urban change and its impact on community access to public spaces.

In addition to these data challenges, user-generated online reviews, particularly from platforms such as Google Reviews, present significant limitations in assessing perceptions of gentrification. Reviews tend to reflect polarized

perspectives, with users either expressing dissatisfaction with specific park features or broadly endorsing park amenities. As a result, nuanced insights into how gentrification affects accessibility and inclusivity are largely absent. Furthermore, because the platform does not prompt users to reflect on displacement or broader social dynamics, it is unlikely that former residents—those most affected by neighborhood change—will document their experiences. This exclusionary bias restricts our ability to assess whether parks have become less welcoming to displaced communities.

Moreover, online reviews disproportionately represent individuals actively engaging on digital platforms, often excluding low-income residents, older populations, and those without internet access. The absence of these voices limits the ability to capture the long-term effects of gentrification on public space accessibility and equity. Additionally, reviewers may not explicitly articulate experiences of exclusion or displacement, making it difficult to extract deeper insights into socio-spatial barriers. These challenges reinforce the need for more inclusive research methodologies incorporating participatory engagement with current and displaced residents to better understand the evolving role of parks in gentrifying neighborhoods.

4.4. Future directions

Given these limitations, future research should aim to develop more comprehensive and transparent methodologies for assessing the socio-spatial effects of gentrification on urban green spaces. A standardized, open-source framework for tracking gentrification in urban parks is needed to support interdisciplinary research and policy interventions. Transparency in data collection—such as public records on park funding, zoning policies, and demographic shifts—can help researchers and planners make informed, equitable decisions.

CONCLUSION

Urban parks significantly reflect and shape the socioeconomic dynamics of rapidly changing neighborhoods. Parks in gentrifying areas frequently offer restorative attributes such as meticulous landscaping and perceived safety, yet grapple with overcrowding and exclusivity. Conversely, parks in economically disadvantaged areas often suffer from poor maintenance, safety issues, and inadequate amenities, limiting their restorative potential and deepening feelings of community neglect. To counteract these disparities, volunteer-driven initiatives could enhance park upkeep and foster community pride and ownership.

While limitations included reliance on passive data from Google reviews, the integration of planning documents and historical records helped provide depth to the analysis. Future research should employ primary methods, like interviews and surveys, to better capture nuanced user experiences. Addressing issues like overcrowding and exclusivity through equitable, inclusive planning could mitigate unintended outcomes like displacement or social stratification, ensuring that parks serve as restorative and inclusive community assets. These findings offer critical insights for urban planners, architects, and policymakers, highlighting the necessity for equitable design and informed investment strategies that prioritize inclusivity and community engagement in park planning.

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Air Quality and Teacher Health in the Context of Energy Poverty in Chile

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ABSTRACT: Current research has found evidence of associations between particulate matter, respiratory diseases, and increases in mortality from all causes. However, most of this data comes from developed countries, whereas studies from middle to low-income countries are limited. In Chile, high levels of Energy Poverty (EP) have been identified in the central-southern towns of the country, where the primary means for household heating are wood stoves. They generate periods of high air pollution during the winter and may exacerbate preexisting health conditions that affect vulnerable populations. Air pollution from EP goes beyond residential buildings and impacts public spaces and buildings near residential areas, like schools. This paper presents an analysis of indoor and outdoor air quality along with a survey of self-reported health symptoms of teachers in public schools in Chile, located in areas of energy poverty. During the winter, indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations were monitored for a school week in three schools in the Gran Concepción metropolitan area in Chile. Particulate matter concentrations were compared with the WHO Air Quality Guidelines (AQG) and local air quality regulations. Indoor and outdoor $PM_{2.5}$ surpassed the AQG recommended levels of air pollution, with the highest concentrations occurring in the evenings and nights. In addition, the survey showed that almost a third of teachers ranked the outdoor air quality in the previous week as "bad," but only 13% saw outdoor air pollution as an important health concern. The symptoms teachers reported as being more frequent included those related to teaching, such as hoarse-dry throat, and respiratory health, like irritated, stuffy, or runny nose. This paper portrays the reality and urgency of Chilean classrooms regarding indoor and outdoor air quality during the winter months and discusses the health implications of teaching and learning in the context of energy poverty.

KEYWORDS: Air Quality, Respiratory Health, Energy Poverty, Schools, Chile

INTRODUCTION

Particulate matter (PM) is one of the classic pollutants considered hazardous by the World Health Organization (WHO). Particulate matter is classified according to size, though its chemical and physical composition might be heterogeneous (World Health Organization 2021). Particles less than 10 μm diameter are coarse or inhalable particles and can be hazardous when deposited in the respiratory tract. In comparison, respirable or fine particles are those smaller than 2.5 μm diameter and represent a hazard because they can infiltrate the gas-exchange region of the lungs (Morakinyo et al. 2016). Previous research has associated both $PM_{2.5}$ and PM_{10} with cardiovascular disease, lung cancer, respiratory problems, and mortality from all causes. However, the current evidence on the health effects of $PM_{2.5}$ and PM_{10} includes very limited studies done in low and middle-income countries (Chen and Hoek 2020), where PM pollution is often a problem due to energy poverty.

For instance, in Chile, energy-poor households are those that do not have equitable access to high-quality energy services to cover the basic needs for the human and economic development of its members (Ministerio de Energía 2021). In the south-central region of the country, this has become an enduring problem, with previous studies finding multiple municipalities at high risk of energy poverty due to heating needs (Pérez-Fargallo et al. 2020). In Chile, over 80% of the households in the southern areas of the country rely on firewood for heating (Corporación de Desarrollo Tecnológico (CDT) 2015; Reyes et al. 2019), which generates significant air pollution due to PM during the winter months. In the municipalities of Concepción and San Pedro de La Paz, 43.3% and 57.4% of households use heating with polluting sources, respectively according to official data. In addition, 50.3% of the households in San Pedro de La Paz and 56% in Concepción are thermally inefficient constructions, increasing the need for heating during the winter (Ministerio de Energía et al. 2024). To address this issue, the Chilean government has strived to reduce air pollution by creating programs for people to use dry firewood and replace wood stoves, which are still insufficient and do not fully address the root of the problem (Reyes et al. 2019).

Furthermore, while the primary source of pollution comes from residential wood stove use during the evenings and nights, the overall air quality decreases in these neighborhoods, impacting nearby public spaces and other facilities like schools. In schools, sources of air pollution can come from indoor and outdoor sources, which is particularly relevant for naturally ventilated classrooms. Some of the primary outdoor sources of PM in schools highlighted in previous literature are high traffic density, emissions from industrial areas, and wildfires. In contrast, indoor sources include chalk dust, particle resuspension due to children's activity, indoor combustion sources (heaters, gas, and wood stoves), cleaning, soil dust, new furniture, and smoking where allowed (Sadrizadeh et al. 2022).

There are many local factors affecting PM concentration levels in school buildings. For example, a study found that summer $PM_{2.5}$ and PM_{10} concentrations were up to 3 times lower than winter concentrations in a naturally ventilated school, and the authors attributed this finding to a lack of ventilation during the cold season (Habil and Taneja 2011). Similarly, other studies have found differences between urban and rural, as well as public and private schools, depending on their immediate surroundings and indoor pollution sources (Branco et al. 2019; Alameddine et al. 2022). In addition, studies looking into social variables such as race and socioeconomic status have pointed out that higher air pollutant concentrations are associated with poverty in specific contexts (Cheeseman et al. 2022). Therefore, assessing PM concentrations in schools can be highly context-dependent and convey different results.

Most studies on indoor air quality in schools have concentrated on the student population and its effects on student health and cognitive performance. In contrast, only a few have examined associations between teachers' health and the classroom's indoor environmental conditions (Lin et al. 2017; 2020; Brink et al. 2021). Teachers spend most of their workday in classrooms, constantly exposed to the indoor air pollutants in these spaces. These exposures may affect teachers' ability to teach through various health symptoms, which indirectly affects children's learning ability. This study focuses on teachers as the primary group of interest. The rationale behind this choice is that teachers are influenced by the school environment just as much as students, and they play a crucial role in shaping classroom environmental conditions. Even more, in elementary school classrooms, students often have to ask for teachers' permission to open or close a window or door. Hence, the indoor environmental conditions of classrooms tend to respond to the teachers' preferences instead of those of students (de Dear et al. 2020). In addition, in lower grades, students might be too young to understand questions related to air quality and health, and parents might be reluctant to provide their permission to participate in the study.

This paper analyses indoor and outdoor $PM_{2.5}$ and PM_{10} concentrations in three public schools in Concepción and SanPedro de La Paz in south-central Chile, along with a survey of teachers' perceptions, self-reported health concerns, and health symptoms in areas of energy poverty, and addresses the following questions (1) How is the air quality in Chilean schools during the winter? (2) How do teachers perceive their health and air quality in schools? (3) How does particulate matter concentrations affect teachers' self-reported health symptoms and concerns?

1.0 METHODS

1.1 The schools

The study was conducted in three public schools in south-central Chile, in the neighboring cities of Concepción and San Pedro de la Paz. The cities are located at -36º 46' 22" latitude and -73º 03' 47" longitude, with an average height above sea level of 12 m (39.4 ft) and are geographically separated by the Biobio River. According to the Köppen Geiger classification, the cities have a Csb climate (Warm-summer Mediterranean climate). Their winter spans from May to August, where July is the coldest month, with an average temperature of 48.2°F (9ºC), and the rainiest month is June, with an average rainfall of 145 mm (Climate-Data.org, n.d.). All schools are in urban residential areas with different immediate contexts. School CH-Z is a two-story building that faces a neighborhood park, school CH-I neighbors a small butte and school CH-G is adjacent to a major highway, with heavy traffic and cargo (Figure 1). All the schools are naturally ventilated and have operable windows.



Figure 1. Schools and sensors' location. Indoor sensor (pink) and outdoor sensor. Source: (Authors 2024)

1.2. Physical measurements

Two neighboring first and second-grade classrooms were selected in each school for the study. In elementary schools in Chile, the same teacher imparts most subjects. Teachers stayed in the classroom with the students most of the time, which helped ensure the equipment's safety and the reliability of teachers' perceptions of the classroom. Depending on the available space, the measuring station was placed in the back or front of the classroom to avoid interrupting classes and to prevent children from tampering with the equipment. Each station was placed from Monday through Friday during the winter of 2023 to gather data on a typical academic week (Table 1). Sensors were moved from school to school every week. Classrooms had normal occupancy in all schools during the measuring week, except for school CH-G, where there was a teacher strike on Wednesday and Thursday, so those days measurements were recorded without occupancy.

A Dylos DC1700-PM air quality monitor recorded indoor $PM_{2.5}$ and PM_{10} mass concentrations ($\mu g/m^3$) every minute. The sensor was located at 0.9 m (3 ft) in height to stay inside the breathable zone of the students and teachers

when they were sitting down. Also, a Purple Air Zen sensor (counting efficiency 50% at 0.3µm & 98% at ≥0.5µm), was installed in an outdoor area of each school during the same week, recording outdoor $PM_{2.5}$ and PM_{10} concentration readings (µg/m^3) every 2 minutes. All data from indoor and outdoor sensors was cleaned and averaged at 10-minute intervals to make it comparable. Due to measurement errors, data from one classroom in school CH-Z and one in CH-G was removed from the analysis. Measurements in the two classrooms in school CH-I were averaged to report and compare them with the results of the classrooms in the other schools.

Table 1: Classroom characteristics and physical measurements summary. Source: (Authors 2024)

School	Dates	Floor	Area m^2 [ft^2]	Max. occupancy	Heating system	Equipment location	
						Indoor	Outdoor
CH-Z	07/17 to 07/21	2	46.5 [500.5]	34	Radiant fan in the back + gas heater (not working)	Front	Interior courtyard façade
CH-I	07/24 to 07/28	1	45.0 [484.4]	25	None	Back	Side façade to green space
		1	45.0 [484.4]	25		Back	
CH-G	07/31 to 08/04	1	37.2 [400.4]	32	Radiant fan in the front + gas heater next to the teacher	Back	Main façade adjacent to the highway

Physical measurement data was analyzed in four different ways. First, statistical tests were conducted using R studio to understand the influence of the immediate context on the school's outdoor PM concentrations. Since the data was not normally distributed, differences between the schools were tested using non-parametric Kruskall-Wallis tests. The following pairwise comparisons were developed using the Dunn procedure, with *p*-values adjusted with the Bonferroni correction. Second, Kendall tau correlations were used to evaluate the association between outdoor air quality (AQ) and indoor air quality (IAQ) in each school. Third, to assess the indoor air quality of each school, the 24-hour average $PM_{2.5}$ and PM_{10} concentrations were compared with international and local standards. Finally, physical measurements were grouped into three 8-hour occupancy periods to assess daily differences in PM concentrations, which represented (1) normal occupancy (class) from 8 am to 3 pm, (2) evening/unoccupied (pm) from 3 pm to midnight, and (3) early morning/unoccupied (am) from midnight to 8 am.

1.3. Surveys

An online questionnaire was distributed to teachers in all schools during the same week of the physical measurements. The questionnaire was based on the MM-040 questionnaire from the Örebro Model (Andersson 1998) and adapted from the long-term thermal comfort assessment survey of the ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 2023) to fit the purpose of this study. In this paper, we only report the results of questions related to teachers' perceptions regarding long-term (last year) and short-term (last week) indoor and outdoor air quality, health concerns, and self-reported health symptoms in the last three months (Table 2). The sample of teachers in each school varied depending on the school's size and the teachers' availability at the time of the survey. A total of 78 responses were received from teachers in the three schools: 36 from school CH-Z, 16 from school CH-I, and 26 from school CH-G, with nine incompletes.

Table 2: Survey questions and measures. Source: (Authors 2024)

Health	Question type	Measure
What do you think of the overall outdoor air quality surrounding the school in the last school year?	5-point acceptability scale	Outdoor air long-term acceptability
How frequently do you find the outdoor air surrounding the school is not acceptable?	5-point frequency scale	Outdoor air acceptability frequency
What do you think of the outdoor air quality surrounding the school in the last week?	5-point acceptability scale	Outdoor air short-term acceptability
What do you think of the indoor air quality of your classroom in the last week?	5-point acceptability scale	Indoor air short-term acceptability
For each of the following potential issues, please rate how much of a concern it is for you in the classroom where you teach.	Matrix - 4-point assessment scale	Health concerns
Have you ever had any of the following respiratory issues?	Matrix - Multiple choice	Previous respiratory health problems
Do you smoke?	Multiple choice	Previous respiratory health influence
During the last 3 months, have you had any of the following symptoms?	Matrix - Multiple choice	Health symptoms & frequency

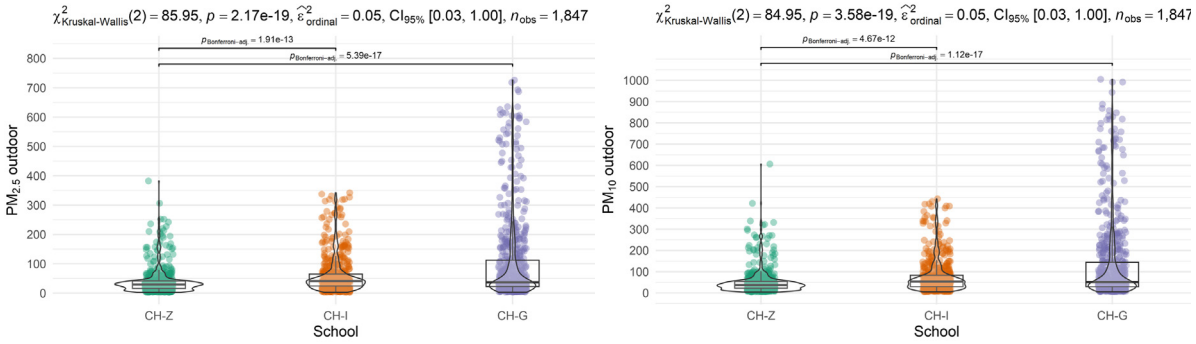
2.0 RESULTS

2.1. Indoor and outdoor air quality in Chilean classrooms

Upon visual examination of outdoor $PM_{2.5}$ and PM_{10} measurements, it was apparent that the data did not follow a normal distribution. Therefore, non-parametric Kruskall-Wallis tests were used to assess differences between the schools, which revealed significant differences in the distributions of $PM_{2.5}$ and PM_{10}. In addition, pairwise comparisons revealed that these differences occurred in all pairings, except for the pair between CH-I and CH-G, even when these two schools have different neighboring contexts (Figures 2 & 3). In all schools indoor PM concentrations were higher than outdoor concentrations, as indoor/outdoor concentration ratios for $PM_{2.5}$ the schools were 1.3 for CH-G, 1.1 for CH-I, and 1.4 for CH-Z. For PM_{10} these were 1.7 for CH-G, 1.6 for CH-I, and 1.9 for CH-Z. In addition, when assessing the correlation between indoor and outdoor air quality, Kendall tau correlations showed that the strength and direction of association between indoor and outdoor $PM_{2.5}$ and PM_{10}

concentrations were positive and significant at the p < 0.001 level. Therefore, outdoor AQ had a substantial influence on classroom IAQ.

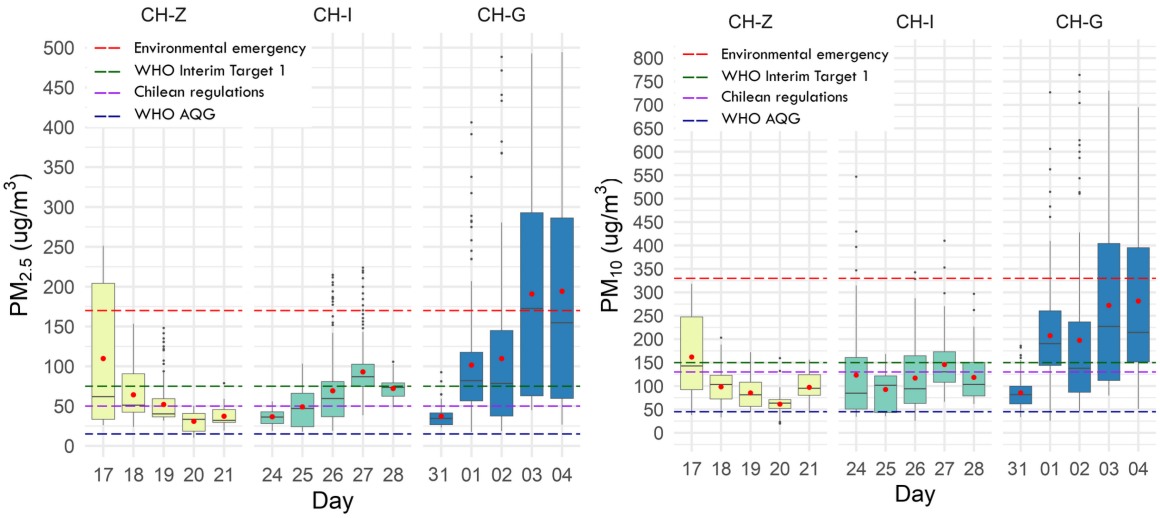
Following these tests, 24-hour averages of indoor $PM_{2.5}$ and PM_{10} concentrations were compared with international and local air quality standards. The latest air quality guidelines (AQG) from the WHO recommended short-term 24-hour exposures to $PM_{2.5}$ at concentrations no larger than 15 µg/m^3 and 45 µg/m^3 for PM_{10}. In addition, the same document establishes interim targets for highly polluted places, with the least stringent being Interim Target 1, with limits of 75 µg/m^3 for $PM_{2.5}$ and 150 µg/m^3 for PM_{10} (World Health Organization 2021).On the other hand, the Chilean Ministry of the Environment defined the Primary Environmental Quality Standard for $PM_{2.5}$ and PM_{10} concentrations in the Decree 12 of 2011 and 2022. The regulation establishes the limits for 24-hour exposures of $PM_{2.5}$ as 50 µg/m^3 and 130 µg/m^3 for PM_{10} (Ministerio de Medio Ambiente 2011; 2022). In addition, the Chilean regulations consider a state of environmental emergency when 24-hour mean PM concentrations are above 170 µg/m^3 for $PM_{2.5}$ and 330 µg/m^3 for PM_{10}.



Figures 2 and 3: Differences in $PM_{2.5}$ and PM_{10} outdoor concentrations for the three schools, respectively. Source: (Authors 2024)

All schools exceeded the most stringent 24-hour AQG of the WHO for $PM_{2.5}$ and PM_{10}, both indoors and outdoors. Since the Chilean local regulations and the Interim Target 1 from the WHO are less strict than the AQG, the schools complied with these standards more often, but not every day (Figures 4 and 5). Even more, the average concentrations of indoor $PM_{2.5}$ recorded in 2 days in school CH-G fell into the environmental emergency category of the Chilean regulations. Interestingly, the school was empty due to the teacher strike on one of those days, meaning that the high $PM_{2.5}$ concentrations were unrelated to any school activities.

When comparing different moments of the day, the average $PM_{2.5}$ concentrations in all schools were lower during class times (Table 3). In addition, in CH-I and CH-Z, the highest average $PM_{2.5}$ concentrations occurred during the evenings, while in CH-G this happened in the early hours of the day. Regarding PM_{10}, in CH-I and CH-Z, the lowest average concentrations occurred in the early morning, while for CH-G, this occurred during class time. The highest average PM_{10} concentrations occurred at different times in each school: in the early morning for CH-G, during class for CH-I, and in the evenings for CH-Z. Even with the occupancy groupings, all schools failed to comply with the WHO AQG while the school was in session. Additionally, CH-G failed to comply with the local regulations during class time, and the average concentration in the early morning fell into the environmental emergency category.



Figures 4 and 5: Daily distribution of indoor $PM_{2.5}$ and PM_{10} measurements in comparison to local and international guidelines. Red dots represent averages. Source: (Authors 2024)

Table 3: Indoor and outdoor $PM_{2.5}$ and PM_{10} average concentrations during different occupancy periods. Source: (Authors 2024)

	Indoor $PM_{2.5}$				Outdoor $PM_{2.5}$			
School	am	class	pm	24-h	am	class	pm	24-h
CH-Z	49.3	38.4	82.3	55.8	27.1	24.2	68.7	39.3
CH-I	64.4	54.1	81	66.2	41.2	34.4	106.1	59.9
CH-G	178.8	76.7	155.8	134.3	119.4	37	149.1	100.8
	Indoor PM_{10}				Outdoor PM_{10}			
CH-Z	74.2	98.8	111.5	95	36.1	31.5	89.2	51.3
CH-I	82	144	128.9	119	54.7	43.8	130.9	75.6
CH-G	262.4	169.9	233.4	219.3	161.4	48.7	190.4	131.8

2.2. Teacher outdoor and indoor air quality perceptions

The first three survey questions inquired about outdoor air quality (AQ), and the fourth inquired about indoor air quality (IAQ) perceptions. Of all the surveyed teachers, 41.3% deemed outdoor AQ acceptable in the last year. Nonetheless, there were differences between the perceptions in each school. In school CH-G teachers had more negative perceptions, with 52.9% perceiving it as either bad or very bad, while in schools CH-I and CH-Z, this only occurred with 6.25% and 20% of teachers, respectively. On the other hand, in school CH-I, 62.5% of the teachers perceived AQ in the last year as good or very good, while this only occurred in 24% of CH-Z and 11.8% of CH-G teachers. Finally, 56% of teachers in school CH-Z, 31.25% in CH-I, and 35.3% in CH-G thought AQ was acceptable.

A total of 37.3% of all teachers reported not finding AQ acceptable either once a month or during a specific period of the year. Nonetheless, following a similar pattern as the previous question, in school CH-G this occurred for 40% of teachers at least once a week. In comparison, in school CH-I, 50% of teachers never or rarely found AQ to be unacceptable. Finally, in CH-Z, 45.8% of teachers found AQ was not acceptable only occasionally.

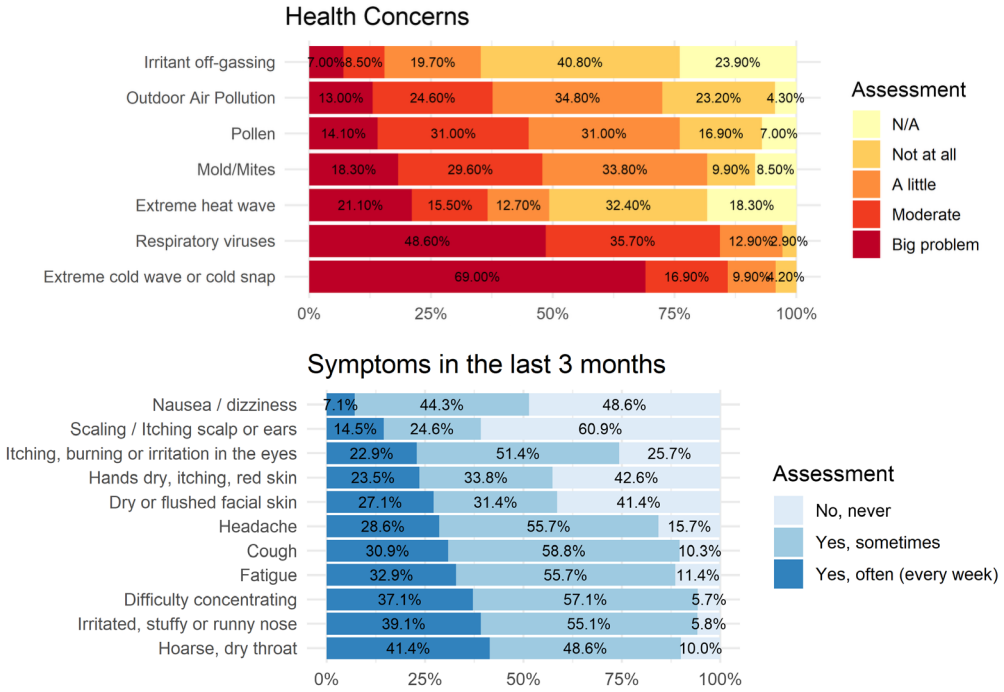
Perceptions about AQ during the week of measurements rendered similar results as general AQ perceptions. Overall, 26.7% of teachers thought AQ was good or very good, 41.3% thought it was acceptable, and 32% thought it was bad. Teachers in school CH-G had the worst perceptions overall, as 52.9% stated AQ was bad during that week, while in schools CH-Z and CH-I, this only occurred with 20% and 6.25% of respondents, respectively. On the contrary, 50% of teachers in school CH-I evaluated AQ in the last week as good or very good, while this only happened with 28% and 14.7% of respondents in schools CH-Z and CH-G. Finally, 52% in CH-Z, 43.7% in CH-I, and 32.35% in CH-G thought AQ was acceptable.

Regarding indoor air quality (IAQ) in the classroom, 42.7% of all teachers considered it acceptable, 38.7% said it was bad, 13.3% very bad, and only 5.3% thought it was good. In this case, teacher perceptions in all schools were more negative than with outdoor air quality. Nearly half the teachers in each school considered IAQ in the classrooms bad or very bad. This perception was distributed among the schools like this: 62.5% in CH-I, 50% in CH-G, and 48% in CH-Z. Nonetheless, a large portion of respondents thought the IAQ was acceptable: 44% in CH-Z, 31.25% in CH-I, and 47.06% in CH-G, while only a small percentage considered the IAQ good: 8% for CH-Z, 6.25% for CH-I, and 5.33% for CH-G.

2.2. Teacher health concerns and symptoms

The main health concerns among teachers were extreme cold waves or cold snaps, as 69% of all respondents considered them a big problem, with similar trends for all schools. Similarly, respiratory viruses were the second health hazard that concerned teachers the most in all schools (48.6%). Also, 21% of all teachers listed heat waves as a big problem, making it the third most frequent response. Interestingly, most of these responses came from school CH-I (40%), while in schools CH-G and CH-Z, heat waves were a problem only for 18.8% and 12.5% of respondents. In addition, heat waves were not a problem for 34.4% of teachers in CH-G and 37.5% in CHZ, while this only occurred for 20% in school CH-I. Therefore, the origin of this concern might be related to a unique characteristic of school CH-I.

Other IAQ problems such as mold or mites, pollen, allergies, outdoor air pollution, or irritant off gassing from paint or other materials were only big problems for under 20% of all respondents. Interestingly, only 13% of respondents considered outdoor air pollution a big problem. Moreover, 34.78% and 46.67% of teachers in schools CH-Z and CH-I did not consider it a problem at all (Figure 6). In addition, 62% of respondents in all schools had never had asthma, but 24% had had it, including the last year. This accounted for 25% of respondents in schools CH-Z and CH-G, while in CH-G, it was only 20%. Regarding hay fever, 54.3% of respondents reported having it during the last year (65.3% in CH-G, 43% in CH-I, and 45.8% in CH-Z). In addition, 60% of respondents reported never having dermatitis, and only 30% reported suffering it during the last year. Finally, 18.3% of teachers reported smoking often, 18.31% smoking occasionally, and 12.68% reported that they used to smoke but did not do it anymore.



Figures 6 and 7: Teacher's health concerns and self-reported health symptoms in the last three months. Source: (Authors 2024)

The most prevailing and frequent health symptoms among teachers in all schools were hoarse or dry throat (41.4%), closely followed by a stuffy, irritated, or runny nose (39.1%), and difficulty concentrating (37.1%), with all schools following similar patterns. On the other hand, the least self-reported symptoms in the last three months were nausea or dizziness (7.1%), scaling or itching of the scalp or ears (14.5%), and itching, burning, or irritation of the eyes (22.9%) (Figure 7).

DISCUSSION

The location of the schools proved to have an influence on daily PM measurements. School CH-G had the highest $PM_{2.5}$ and PM_{10} concentrations, likely due to its location near a major highway. Nonetheless, the lack of significant differences between the distribution of PM concentrations in school CH-I and CH-G revealed that other sources of pollution are ubiquitous in both cases. In the case of Concepción and San Pedro de la Paz, this can be explained by the prevalence of firewood stoves in both cities, which generates PM pollution during the colder moments of the day all over the city.

Indoor and outdoor air quality were significantly correlated, indicating that outdoor PM has a major influence on IAQ. All the schools included in this study are naturally ventilated, have leaky envelopes, and have old windows that sometimes do not close properly, making indoor and outdoor conditions highly correlated. What is problematic though, is that outdoor air conditions surpassed the WHO guidelines and, on occasion, reached environmental emergency conditions. Public schools in these cities do not have on-site tools to monitor indoor and outdoor air quality. Therefore, they must rely on the few governmental stations available, which might not account for localized conditions. Consequently, schools cannot keep records of their air quality and do not have the tools to take any action towards improving it.

Data analysis using 8-hour periods allowed us to address differences in PM concentrations at different moments of the day. Average $PM_{2.5}$ and PM_{10} concentrations were higher indoors than outdoors during class time. Teachers kept the door, and most windows closed to preserve the warmth inside and avoid noise coming from outside, which can cause the resuspension of PM inside the classroom and a lack of air renovation during the day. In addition, some classrooms used a radiant fan for heating for a couple of hours in the morning, which might increase PM resuspension and decrease IAQ.

Class periods represented the lowest average $PM_{2.5}$ concentrations in every school. In contrast, evening periods had the highest $PM_{2.5}$ concentrations in CH-I and CH-Z, corresponding with the moments when residential areas turn on the woodstoves for heating. In contrast, in school CH-G, the highest $PM_{2.5}$ average concentrations occurred in the early morning, possibly due to early morning traffic on the highway. In addition, the average $PM_{2.5}$ concentration in CH-G in the evenings was still higher than that of the other two schools, and reached pre-emergency levels according to Chilean regulations (Ministerio de Medio Ambiente 2011; 2022). These results show how PM impacts come mainly from neighboring sources, including the highway and the residential areas adjacent to the schools. The high evening PM records correspond with issues related to city-wide energy poverty. Even when

occupants' exposure to $PM_{2.5}$ is lower during regular class times, they are likely still exposed to high pollution levels when not at school.

Teachers' general outdoor AQ perceptions showed differences between schools. While over half the teachers in school CH-G perceived it as mostly negative in the last year and last week, for school CH-I, general perceptions were mainly positive. However, the physical measurements presented a different story, showing that while the AQ in CH-G was worse than CH-I, it was not ideal either in CH-I, given the overarching impact of wood burning in the area, especially during the evenings. In this case, these perceptions might be related to the school having a large green area and neighboring a butte instead of a major highway. Teachers might associate seeing greenery next to the school with perceiving good AQ.

Indoor air quality perceptions proved to be more negative than outdoor AQ perceptions in all schools. In this case, responses in all schools rendered very similar results despite the differences in PM concentrations evidenced by physical measurements. Even in CH-Z, where the indoor PM concentrations were lower compared with the other two schools, almost half the teachers considered the air quality as bad or very bad. In this case, teachers' perceptions might be coming from a different origin. Since the project was developed during the winter, the most concerning health hazards reported were cold snaps and respiratory viruses. Therefore, teachers might have been associating IAQ with cold indoor air temperatures in the classroom and viruses due to crowdedness, instead of PM concentrations.

General health questions and self-reported health symptoms had similar response trends in all schools. The most frequently reported symptoms were related to teaching, such as hoarse and dry throat, which corresponds with previous findings (Brink et al. 2021). Respiratory symptoms were also reported as being frequent, which might be related to the overall poor air quality in the city and the low temperatures during the winter. Since the study only covered the teacher's time at school, it was not possible to assess other influences they were exposed to during other periods, which might be the most critical for PM exposure times, as shown by the physical measurements.

CONCLUSIONS

The study analyzed PM pollution concentrations on air quality in school facilities in Concepcion and San Pedro de La Paz. The results showed high indoor and outdoor PM concentrations, evidencing the prevalence of energy poverty in south-central Chile. The use of wood stoves for heating in residential areas neighboring the schools was the main source of PM pollution, as concentrations spiked during the evenings and nights. These results highlight the urgency to improve current energy sources. The current Plan for Prevention and Atmospheric Decontamination (PPDA) of the Concepcion Metropolitan region, includes actions such as improving the type of wood for heating, upgrading heating devices, and enhancing the energy efficiency of dwellings (Ministerio del Medio Ambiente 2019). Despite the formulation of the plan years before the development of this research, our results show that the efficacy of its execution is not yielding visible results yet. Studies like this one provide further proof to a call for action on this matter to bring this forward to the political scene.

Future research could further investigate low-cost sustainable technologies and strategies suitable to the local context to replace the current wood burning stoves, as well as affordable ways to increase the energy efficiency of the existing residential building stock. For instance, studies have shown that for low and middle income households, retrofitting traditional woodstoves can improve their performance and reduce emissions (Carvalho et al. 2018). Also, modern woodstoves or pellet stoves have been found to emit lower quantities of particulate material than traditional woodstoves (Bäfver et al. 2011), when other heating sources are not economically feasible.

The research also showed that teachers' perceptions of air quality did not always correspond with the physical measurements. A high percentage of the sample did not consider outdoor air pollution a significant health hazard. Teachers are accustomed to living in the same polluted conditions every winter, so they may not perceive it as a risk. As the health effects of air pollution occur only after chronic long-time exposure, people might not consider it an imminent threat. Nonetheless, Chile suffers approximately 4000 premature deaths every year due to air pollution (United Nations Environment Programme 2017), and the prevalence of energy poverty makes it an even more pressing situation.

These results provide a general idea of the indoor and outdoor air quality conditions in the south-central region of Chile and unveil the existing disconnect between air quality conditions and air quality perceptions. The study was limited by only exploring teacher's exposures during their time at school and a short measuring period, so it was not possible to define a clear relationship between PM exposures and self-reported health symptoms. Nonetheless, since high PM pollution occurs all over the city, teachers are likely exposed to high PM concentrations outside school hours. Future research using mobile sensors could shed more light on the effects of daily PM exposures on personal health.

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The Rhythm Analysis of Liminal Urbanisation: Migrants' Decision-making through Multiple Temporalities

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ABSTRACT: Liminal urbanisation represents a bottom-up communal organisation of self-built dwellings, established through the social interdependence of neighbours. A study of forced migrants from Kosovo and North Macedonia inhabiting the periphery of Montenegrin coastal cities reveals spatial, temporal and social splintering of conventional decision-making processes. This fragmentation manifests through linear recurrence, cyclical repetitiveness and periodisation, which together form the spatiotemporal framework of these neighbourhoods. Linear recurrence encompasses activities during dwelling construction, whilst cyclical temporalities are shaped by communal activities in public spaces. Periodisation represents a set of social peaks that generate horizontal decision-making. The author employs qualitative methods, including questionnaires, semi-structured interviews, focused observation and informal conversations with participants from four informal neighbourhoods: Bijela Gora, Palestine, 7th July and Meljine. The study demonstrates how political empowerment of migrants emerges through their demands for affordable housing and social inclusion, ultimately challenging authorities' top-down perspectives on informal neighbourhoods.

KEYWORDS: Henri Lefebvre, linear rhythm, cyclical repetition, periodisation, Roma, Ashkali and Egyptian inhabitants.

INTRODUCTION

Unlike analyses of social struggles in informally built neighbourhoods through Manuel Castells' structuralist lens or David Harvey's neoclassical approach, Henri Lefebvre recognises that timescales, through a multiplicity of rhythms, determine spatial and social dynamics (Kipfer et al. 2012). The philosopher asserts that "rhythm exists wherever there is interaction between a place, a time and an expenditure of energy" (Lefebvre 2013, 26). This rhythm analysis involves tracing changes in communal activities and becoming attuned to them "as an audience listens to a symphony" (Lefebvre 2013, 96).

I employ rhythm analysis to study migrants' socialisation and decision-making processes in neighbourhoods by capturing different recurrences. For Lefebvre, rhythm is inextricably linked to understanding repetition (Goonewardena et al. 2008). Repetition involves duplicating activities and situations that embrace personal and communal differences through informal building, adjusting barriers and organising neighbourhoods. These repetitions achieve completion through "duration and intensity", ensuring that "time lingers" above its roots in class, race, ethnicity and gender (Han 2020, 8). In informal communities, mechanical or planned replication "entails operations that are not only stereotyped but also consecrated rites" (Lefebvre 2013, 39). These recurrences, as productive activities, "can only be thought of as the repetition of difference", which creates possibilities for community occupants (Hallward 2006, 71). This mode of communal productivity "generates constant newness within continuity" (Gardiner 2012, 43). Drawing from Lefebvre's modalities of rhythm, I captured the linear and cyclical repetitive everyday activities of migrants' socialisation in liminal neighbourhoods.
Liminal urbanisation creates subaltern, open-ended areas characterised by informal dwellings and the social differences of their inhabitants (Dale & Burrell 2008). These areas, lacking documented street names, legal parcellation and legitimation, form an irregular morphology of continuous expansion through "transitory dwellings" built with recycled materials and without formalised sanitation infrastructure (Shortt 2015, 645). The occupation of these residences challenges the conventional separation of "living, working, and amenities" and transcends social boundaries and expectations, highlighting the importance of spatial-temporal analysis (Van den Hoek 2009, 10). Liminal communities foster "fertile ground for bottom-up democratic practices and political participation" (Rocco & van Ballegooijen 2019, 6). The inhabitants' interdependence emerges as the most striking aspect of these districts, with migrants' involvement in self-building and communal gatherings extending beyond the available representation of horizontal alliances in studied communities.

In contrast to univalent dynamics in self-built neighbourhoods, I employ linear and cyclical repetitions as spatiotemporal characteristics of migrants: linear rhythm concerning their activities during barrack construction, and cyclical occurrences through neighbour interactions in self-constructed neighbourhoods. These two measurements integrate the spatial and temporal dimensions of migrants' inhabitation. Periodisation, emerging as a set of social peaks from these recurrences, signifies multiple temporalities of social and political non-hierarchical dynamics. It relates to thresholds being erased and replaced by accelerated communication aimed at overcoming social and political restraints. This raises two key questions: How do migrants' linear and cyclical repetition during barrack construction and socialisation in public spaces influence different political periodisation?

And how do their everyday activities contribute to horizontal decision-making? Temporal urban liminality examines the migrants' social "roles played by ambivalence and hybridity in everyday life", which affect their economic, sociospatial and spatiotemporal aspects (Mady 2024, 2).

Whilst this study does not address how affluent individuals and political leaders replicate informal urbanisation models, it demonstrates how self-organised adjustment of communal spaces evolved through time patterns punctuated by ruptures, breaks and crises. In critiquing the understanding of time in informal urban areas as a continuous stream of events—such as building rudimentary units, adding recycled material, extending rooms and finishing facades—I traced overlapping timescales of households' investments in alternating sheds and socialising in parking lots and common spaces. Constant building and repair emerge as outcomes of the trial-and-error process in these communities, revealing the cyclical nature of self-building. Considering the interdependence of families isolated from broader society, time spent in communal spaces adjacent to streets and between barracks reveals migrants' resistance to the productive mode of workday expectation (Sharma 2014).

This study has two primary objectives. The first is to capture different spatiotemporal dynamics in four informal neighbourhoods in Montenegro's coastal cities. This section introduces the concept of urban liminality and its application to migrants from Kosovo and North Macedonia through a literature review of self-built dwellings, linear and cyclical repetition, and periodisation. The second objective traces cyclical versus linear repetition in migrants' communities, punctuated with periodisation as the rupturing and reweaving of horizontal decision-making. The outcome is a spatiotemporal analysis of informal neighbourhoods that traces the political potential of migrants' struggle for affordable housing upgrades, challenging local and government elected officials' top-down views. Participants' critique of authorities and desire to alter their social status affirm the Lefebvrean calls for the right to co-develop liminal districts.

1.0 LITERATURE REVIEW

1.1 Self-built Dwellings as Groundwork of Liminal Urbanisation

A shelter is self-built if the household is involved in the construction by participative decision-making without the involvement of professionals. This mode of inhabitation disrupts existing and outmoded forms of housing provision and finds adaptive solutions for migrants to "devise their own, bottom-up solutions" of urbanisation (Pearson *et al*. 2020, 286). This self-construction necessitates decades-long desirable and viable alternation of shacks used to form solidarity among neighbours (Lombard *et al*. 2021). Their inventions are grounded on social practices encapsulated in building imagination and social organisation for the growth of liminal neighbourhoods. These neighbourhoods embody the spatiotemporal alternation of urban tissue based on the decentralised organisation of communities as the essence of horizontal decision-making (Obremski & Carter 2019).

The Latin word *limen*, signifying threshold or boundary, explores occurrences of between-ness or inhabiting margins as opposed to a supposed "centre" or living in a temporary state (Cacciotti 2024). There are "degrees of liminality" that "weighed against persisting spatiotemporality " as the pre-liminal, characterised by separation and segregation of citizens, the liminal as transition, and the post-liminal as reintegration and aggregation of occupants (Turner 1979, 466; Bjørn 2009, 18; Chittenden 2021). The last category is beyond the scope of this study since forced migrants have not achieved acceptance from citizens from other neighbourhoods.

Urban liminality is a space-time repetitiveness of events which facilitates the constant adaptation of neighbourhoods (Pavoni 2020). This liminality encompasses social degradation, the danger of segregation, ecological pollution and multiple scenarios for political manipulation (Lancione & Simone 2021). These liminal transformations depend on "new processes, forms, structures, patterns, experiences and entities" as the foundation of urban growth in all cities (Stenner 2017, 16). I captured these processes through linear, cyclical repetition and punctuation that is "simultaneously destructive and constructive" and suspends "known norms, behaviours and identities" for giving way to improvisation, uncertainty, and experimentation (Shortt 2015, 637).

1.2. Linear and Cyclical Repetition

Repletion is governed by changes that create variations or differences in "their amplitude," frequency, and the energies deployed (Lefebvre 2014a, 206). This strength recorded in liminal urban districts is shown through Roma, Ashkali and Egyptian (RAE) migrants' daily adjustment of barracks and time spent negotiating with neighbours. Recurrences result from socialisation between disadvantaged households through sharing construction knowledge that "constitute[s] time" dynamics and investments (Lager *et al*. 2016; Meij *et al*. 2021, 1822). I used these repetitive activities to gain insight into the multiplicities of timescales in self-built neighbourhoods captured through the linear and cyclical processes.

Migrants' repetitive working day cycles, obligation patterns, and gatherings for discussing self-building in the neighbourhood create a time flow that contributes to linear repetition. This "linear comes rather from social practice" during the construction and adjustment of dwellings. It derives from "a series of [hourly, daily, weekly, and monthly] gestures" that "constrained and colonised" communal relations (Simonsen 2005, 8). On one side, linear repetition results in "lassitude, boredom and fatigue", and on the other, it is "amenable to being fully quantified and homogenised" households, resulting in "more activities, distractions, visual stimuli and entertainments" in informal neighbourhoods (Lefebvre 2014b, 129-130; Gardiner 2012, 46). Migrants' cyclical recurrence exudes differences in communities through exposure to relationships between neighbours. This cumulative socialisation is conditioned by "active and passive, days and nights, " and accepted and rejected practices (Lefebvre 2013, 8). This temporality

is measured as continuous communication, dependence and reliance on neighbours in car parks and communities for sharing work-related information. The target of these activities is not "routine or repetition as such", but it is central to steering the communal horizontal decision-making regarding future housing upgrades (Gardiner 2004, 238).

1.3. Periodisation

These two rhythms are joined "together because they enter into perpetual interaction and are even relative to one another, to the extent that one serves as the measure of the other" and construct periodisation (Lefebvre 2013, 90). Periodisation is a useful metronome for examining the articulations of neighbourly relations (Brenner 2009). It represents a capacity to blend linear and cyclical assemblages of migrants with the changing political climates. Periodisation represents an ongoing rupturing and reweaving of marginalised groups' organisations for "negotiating fluid spatial articulations and priorities" through interhuman dependence (Salder 2020, 1039). It frames noteworthy social conjunctures, spatial contexts, and communities' past and present challenges through horizontal decision-making (Jessop 2019; Ghulyan 2019, 3). This "periodisation of space based on the general production methods" influences social patterns in communities through "which these production methods prevailed" (Şekerci & Örmecioğlu 2020, 590). Since it depends on changing spatial and temporal properties of liminal neighbourhoods, "there can be no master periodisation that captures the essence of a period for all purposes" (Jessop 2003, 3). Thus, the periodisation of multiple levels of socialisation during self-building and communal gatherings in public areas pursues appropriate and optimal urban spatiotemporal articulation (Addie 2022). It redefines "spatial hierarchies" that oppose the dominant mode of city governance (Salder 2020, 1039).

2.0 METHODOLOGY

I completed ethnomethodology from January 2017 until March 2024. Ethnomethodology examines methods that allow group members to manage and organise inhabited places (Whittle 2018; Garfinkel 2023). The qualitative data was collected through questionnaires, semi-structured interviews, focused observation, and informal conversations with participants from four informal neighbourhoods. These methods enabled me to see how migrants' spatial adjustments were timed and shared among neighbours. Migrants' time invested in self-building and community activities was embodied by my field book sketches and recorded narratives. Their sociological and temporal perspectives are entrenched in spatial measurements, the importance of timescales, and enthusiasm when asked about linear, cyclical repetition and periodisation of everyday life (Button 1991). This rhythm analysis is voiced through "undomesticated forces" that cannot be measured by income levels, construction skills, and educational level (Simone 2018, 19), which should be the subject of future investigation.
My field notes in Ulcinj, Budva, Tivat and Herceg Novi were compiled based on approximately 800 hours spent communicating and discussing spatiotemporal topics with community leaders and migrant families. These notes include how I met and interacted with the participants, the atmospheres and materiality of the public places, how interviews proceeded, and talk when the delivered questionnaires were collected. Weekly visits were conducted when government regulations were permitted to combat the spread of the COVID-19 pandemic. Alongside observing neighbourhoods, I collected 46 interviews and 73 questionnaires. Over 80% of the interviewed participants were female, and the identities of the participants are confidential. I applied principles of non-maleficence, faithfulness, integrity, justice, and respect for human rights and dignity during fieldwork provided in the International Communication Association's Code of Ethics, which brings normative research questions to ongoing analyses (Provoost 2020).

3.0 FOUR CASE STUDIES

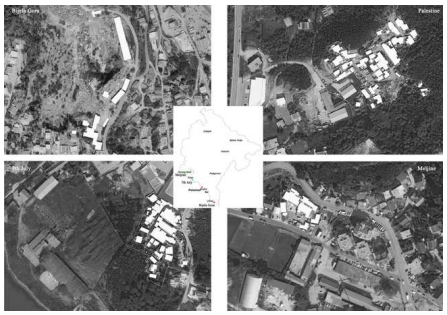
This research explores four informal neighbourhoods: Bijela Gora in Ulcinj, Palestine in Budva, 7th July in Tivat, and Meljine in Herceg Novi, located on the periphery of these cities. These districts were selected because they house most of the vulnerable groups in the southern region of Montenegro. Palestine and 7th July are the two largest neighbourhoods, and the most vulnerable families and individuals inhabit Bijela Gora and Meljine.
Bijela Gora in Ulcinj, the coastal city on the east border of the country, is located on the top of the hill 2 km northeast of the old town (figure 1). Families inhabited the decrepit buildings of a former aluminium factory that closed in 2008 when the director informed displaced families that the structure was available for occupation (figure 2). The building was left without windows and doors; consequently, migrants inhabited them by covering window frames with cardboard and other recycled materials. The spatial void of these buildings represents a challenge for households' intimacy, and the 10-meter-high ceiling obscures adequate heating during the winter season. This area is inhabited by a fluctuating RAE population from 9 to 20 households and individuals performing temporary work during the summer. The public place is covered with leftovers produced by a family over many years and materials from construction companies using the ground to dispose of their surplus illegally.

Palestine is 5 km west of Budva's old town and 1.6 km from Jaz beach. In 1985, this locale was formed between hills hidden from the main road, with two long shacks as transitory accommodation for RAE migrants from Kosovo and North Macedonia (figure 1). In 1993, ten migrant families started to inhabit these shacks permanently. Only one shack survived the fire in 1999, which initiated the informal construction cycle (figure 2). This neighbourhood contains 56 households, four from Montenegro, and the others are RAE refugees from Kosovo. After the initiation of informal settlement, the members of political parties downgraded migrants' religion and ethnicity by labelling them as Palestine people.

7th July, 16.8 km northwest of Palestine, is located at Tivat's east entrance, 1.5 km from the airport and 2 km from the downtown (figure 1). In 1990, the RAE refugees occupied the hill's northern slope; today, 35 families have

settled in this community (figure 2). This neighbourhood contains three large-scale collective shacks built as temporary accommodations for temporary workers that were transformed into permanent living units. Inhabitants adopted a more politically neutral name for the neighbourhood, marking the date the first household inhabited the neighbourhood.

Meljine in Herceg Novi, the coastal city on the west border of the country, is located at the east entrance of the city, 2.2 km away from the old town (figure 1). This settlement was established in the 1990s for the seasonal labourers and their families, and in 1999, it was occupied by refugees from Kosovo and North Macedonia. Today, these dwellings are occupied by 11 RAE families and two single residents from Montenegro, older than 50 years and mostly unable to work due to illness or work-related injuries. These units share a common wall, and the dwellers adjust the facades and extended units (figure 2). Since the local government owns the land, this housing solution is the only stability families have, and they fear being pushed or forcefully moved out.



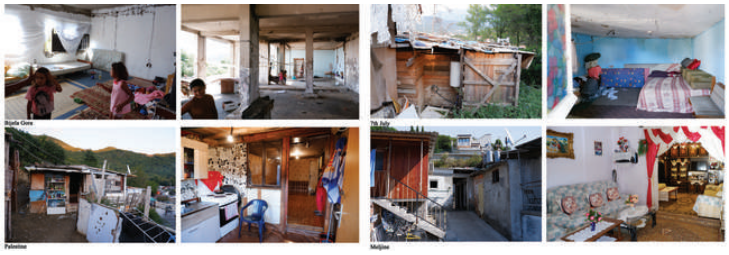


Figure 1 (left): Map of Montenegro with four case studies (central). Drone photography of Bijela Gora (left up), Palestine (right up), 7th July (left down) and Meljine (right down). Source: (Author, 2025)

Figure 2 (right): Photography of Bijela Gora (up left), Palestine (down left), 7th July (up right), Meljine (down right). Source: (Author, 2020/1)

4.0 MIGRANTS' LINEAR AND CYCLICAL RECURRENCES

Table 1: Tracing alternation of dwellings and collective places in Bijela Gora, Palestine, 7th July and Meljine. Source: (Author 2023)

Places	No. of units				Timed activities (%)				Recorded alternation of places (%)			
	BG	P	7J	M	BG	P	7J	M	BG	P	7J	M
Sheds	09	56	35	11	74	51	47	67	04↑/13↓/83O	49↑/24↓/27O	41↑/29↓/30O	22↑/02↓/76 O
Repaired sheds	01	43	29	08	03	12	17	10	• /• /•	• /• /•	• /• /•	• /• /•
Car parks	01	03	02	01	09	11	15	07	• /43↓ /67O	44↑/18↓/38O	47↑/• /63O	05↑/• /95O
Collective courtyards	03	04	03	01	14	36	21	16	11↑/ • /89O	48↑/11↓/59O	30↑/06↓/64O	12↑/02↓/86 O

BG – *Bijela Gora*; **P** – *Palestine*; **7J** – *7th July*; **M** – *Meljine neighbourhoods*; ↑ - *explosion*; ↓ - *implosion*; O - *no changes*; • - *no data.*

Sheds' extensions determine how the spatial arrangement alters social-temporal interactions between neighbours (Lefebvre 2013). Bijela Gora has nine permanent living families and eleven temporary squatters, leaving these shelters decaying and out of repair (Table 1). In Palestine, 43 houses have at least undergone one repair cycle, while in 7th July 29 households repaired their barrack multiple times. An inhabitant stated, "In acceptance of our traditional ways of life, we persist in extending our shelters in agreement with neighbours" (March 2021 interview). In Meljine 8 families invested additional time and effort in repairing their dwelling. Bijela Gora and Meljine families did not invest in larger alternation and focused on the interior finishing. This passive inhabitation is captured by a statement from a community founder of Bijela Gora: "The big problem for us is that new migrants are just desperate and move in shelters without adjusting their shelter or front yards" (April 2018 interview). Half of the participants extended their shelter in Palestine by adding up to two rooms, and 41% of participants from 7th July followed this logic (Table 1). Almost one-quarter of subjects in Palestine imploded initially built units by demolishing walls for larger interior spaces, while nearly a third of interviewees on 7th July did the same. A third of the households in both neighbourhoods, 27% in Palestine and 30% in 7th July kept the initially built building with negligible maintenance.

These alternations of dwellings enforce linear repetition of construction processes, moulding neighbourly dependence. Families' time invested in self-building overcomes the categorisation of incremental phases, such as inhabiting basic single-room shelter, extending a room, adding additional rooms, rearranging interior partisans, altering roofs, facades and verandas and adjusting courtyards. In opposition to these phases, traced temporalities during the building of barracks revealed a series of repetitions that resulted in boredom and fatigue of less involved family members and strengthened communal relations of active participants by producing visually and material stimulating shelter envelopes. Building techniques of bricklaying are recorded in no unit in Bijela Gora, four barracks in Palestine, three in 7th July, and one in Meljine. Other households used to overlap recycled materials and water isolation layers which know-how was shared through dilogies during leisure time.

Communal activities in the Bijela Gora peaked from 5 a.m. until 9 a.m., while the rest of the day I recorded low or no happenings among neighbours (figure 3). Palestine and 7th July neighbourhoods are more active, having longer socialisation time from 4 a.m. until 1 p.m. and a medium level of interaction after 3 p.m. Interaction among inhabitants in Meljine is the most dynamic between 5 p.m. and 9 p.m., and the rest of the day is passive. These communal cycles directly impact the self-built sheds since their envelopes and spaces between them are appropriated for gatherings.

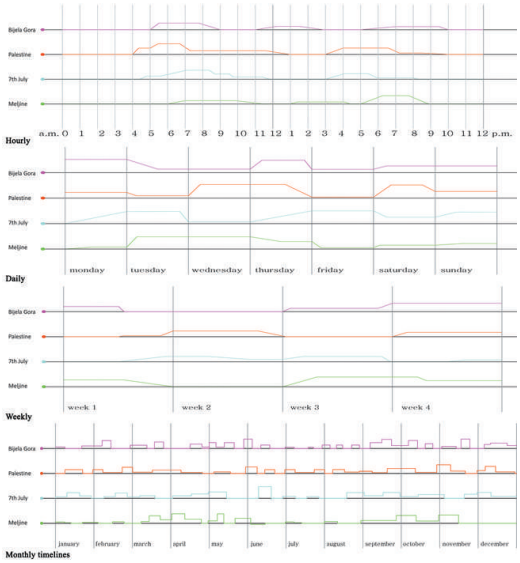


Figure 3: Hourly, daily, weekly and monthly timelines of self-building in four case studies. Source: (Author, 2025)

In Bijela Gora, inhabitants tend to put additional effort into enveloping their shelters on Monday and Thursday (figure 3). In Palestine, exceptional self-building days are Wednesday, Thursday and Saturday, while in the 7th July are Tuesday, Friday and Sunday. Households of Meljine on average engage with the living environment on Tuesday and Wednesday, and the rest of the week holds minor interaction. In Bijela Gora, self-building activities are dominant in the first half of the first week and continue in the third and fourth week of the month (figure 3). Palestine timeframes for building are recorded on the second and fourth weeks, while 7th July occupants worked on sheds the most on the second and third weeks. Meljine intensified activities most of the first week and the third and fourth weeks. These patterns created yearly construction codes repeated multiple times in the last three decades. Each repetition established differences in the outline and envelope of the liminal shelter. Timeframes in Bijela Gora revealed that throughout the year building was done sporadically in intervals up to 10 days (figure 3). In Palestine and 7th July neighbourhoods, cycles of self-construction result in more continuous work throughout the year. In Meljine, work on shelters was done mostly in spring and autumn. In general, fewer active months are in the summer season when most of the participants work long hours in multiple seasonal jobs. From one side, the traced linear timelines of self-building led to self-reliance reflected through a critique of the municipal authorities. On the other, it initiated a strong neighbouring interdependence leading toward horizontal decision-making in four communities. This dependence is recorded via dialogues between households for sharing building know-how accounting for 34% of the recorded time invested in a building in Bijela Gora, 65% in Palestine, 53% in 7th July, and 37% in Meljine. According to the interviewee from 7th July, this "construction and maintenance depends on internal agreements resulting from social conditions and time investments based on economic power of families" (June 2021 interview). These time investments enable migrants to be fully homogenised, resulting in commitment and dependence on each other.

Cyclical recurrences depend on active and passive moments, day and night activities, and accepted and jugged use of public areas. It occurs in car parks and community courtyards where music, games, laundry, gardening, mechanical reparation and recycling materials are performed for sharing community and work-related information establishing reliance on neighbours. Bijela Gora residents park cars between junk, and there are three common gathering areas (Table 1). "All neighbours park their vehicle in front of the barrack. I like marking territory with my car to protect my family's belongings" (July 2023 questionnaire). In these public areas, 29% of active sharing of information and engagement was recorded. From 8 p.m. until 6 a.m., the community is predominantly inactive, and the most recorded communal engagement is from 10 a.m. until 1:30 p.m. (figure 4). In the central zone of Palestine, there is one car park with recycled steel frames, the first business in the neighbourhood, two smaller parking spaces and four community courtyards on the periphery. These areas hold 71% of all active participation of inhabitants which is conditioned with gatherings after 7 p.m. when all participants finish their working day, and daily interaction from 7 a.m. until 4 p.m. 7th July has a smaller parking lot on the north perimeter, a medium-sized on the southeast boundary, one courtyard for community interaction, and two gathering places are on the main internal street. These public places generate 59% of interaction among migrants integrated with two timeframes from 6:30 p.m. until 9 p.m. and from 9 a.m. until 1 p.m. The Meljine community has one parking lot used for community gatherings, which generates 23% of cyclical recurrences. From 10 a.m. until 11:30 a.m. and 4 p.m. until 7 p.m. is marked with neighbours' communication and the rest of the time inhabitants stay inactive. The social benefit of these timeframes is captured through the interviewees' emphasis on music, games, laundry, gardening, mechanical reparation and recycling materials.

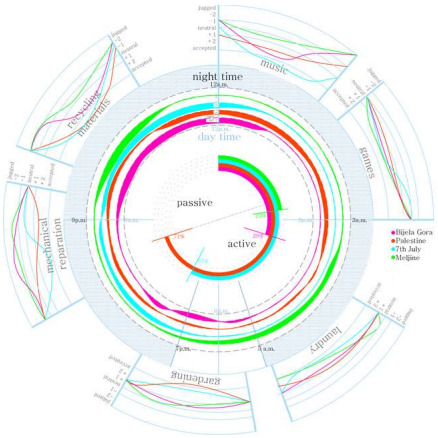


Figure 4: Cyclical timelines in four communities. Source: (Author, 2024)

Concerning neighbourly relationships in public places, I traced that most of the surveyed migrants in Meljine jugged used loud music, while in the other three case studies the tolerance was higher (figure 4). All participants expressed neutral and slight approval of games in shared areas. The higher reception rate was using common places for laundry and display of household items, and even higher was assigned to gardening which was viewed as beautification of the communities. In Bijela Gora and Meljine repairs were viewed as an obstacle to the community growth, on the contrary, it was an asset to the diversification of activities in Palestine and 7th July. Similar divided views follow recycling and storing materials in public places, as inhabitants of Bijela Gora and Meljine stated that it "created an intolerable hazard in the community" (May 2021, questionnaire in Bijela Gora). This acceptance and judgment unveil the uneven opportunities between households, which outcome is a mode of horizontal decision-making aiming at the right to coproduce housing upgrading projects.

5.0 PERIODISATION TOWARD HORIZONTAL DECISION-MAKING

Assembling linear and cyclical temporalities compose periodisation as an apparatus for horizontal decision-making dynamics. In four case studies, uneven opportunities between family members during self-building and household attending community gatherings strengthened dependence on neighbours and critique of community leaders.

Apart from four households in Palestine and three in 7th July that used bricklaying, the rest of the participants established a neighbourly relationship through sharing knowledge of different techniques of overlapping recycled materials and water isolation layers. This self-building know-how influenced weekly, monthly and yearly repetitions through households' mistrust of local and governmental authorities leading toward horizontal decision-making. This horizontality is viewed in a self-organised cluster of households: two in Bijela Gora, six in Palestine, four in 7th July, and one recorded in Meljine. These groups share meals, construction knowledge, and assist neighbours in repairs of barracks after a storm. These collectives influence decision-making in neighbourhoods by restraining community leaders who are in all cases affiliated with political parties. These limitations shared among clusters strengthen the social bonds of households and reveal their struggle for spatial and political changes in liminal communities.

Gatherings in public places revealed uneven opportunities between households where information about community organisations is distorted and misunderstood. This imbalanced socialisation forced participants to negotiate and accept compromise for the next cycle of communal activities. These cycles of negotiations derive from participants' opposing views of poverty and marginalisation, but they are unified by critiquing municipal leaders and government officials for using their migratory status as a cheap working force. This "enslaved position" (April 2024 interview in Palestine) deprives these communities of urban facilities and isolates migrants from the rest of society. In four cities the local government delivered holiday gifts to children, basic food packages, and improved roads during election campaigns, but did not address the long-term social, ethnic, and political exclusion of RAE households and housing upgrade strategies. This top-down view of marginalisation prolonged the liminal status of these communities and motivated migrants to initiate political changes.

In Palestine and 7th July, more than in Bijela Gora and Meljine, there is political potential for channelling inhabitants' dissatisfaction in the form of bottom-up initiation of social housing projects. This potential confirmed the Lefebvrean calls for migrants' right to coproduce horizontal "political and legal apparatus" by contesting the political establishment (King 2019, 77). This governance from the below enables the RAE population to appropriate the self-building of shelters in the open-ended social housing and community relationships into a non-authoritarian and "inclusive democratic communication and decision-making" (Young 2002, 6). This decision-making is assembled "with its many threshold experiences and its tendency to incorporate older forms" of governance within the communal framework of self-building (Eiland & Jennings 2014, 8).

CONCLUSION

I examined how linear and cyclical repetition combine to form periodisation, revealing political potential through migrants' self-organisational skills. This self-reliance manifests as "movement-stasis, proceeding-waiting, acceleration-delay", which suspends conditions of social marginality (Baumann 2019, 45). The recorded household

alliances demonstrate their struggle for spatial and political changes in liminal communities. The spatiotemporal dynamics studied across four Montenegrin informal neighbourhoods emerge through migrants' linear and cyclical repetitions, as well as periodisation during barrack construction and socialisation in public spaces.

The alternation of barracks introduced socialisation patterns varying across neighbourhoods: 34% of the yearly recorded time flow in Bijela Gora, 65% in Palestine, 53% in 7th July, and 37% in Meljine. Migrants' investment in self-produced shelters revealed political punctuation within established household clusters. These groups shared building expertise and critiques of community leadership through family networks. Their alliances formed through linear recurrences of experimenting with different construction techniques, building social consciousness and awareness of minority group empowerment. Whilst these sequences do not contribute to a coherent resolution of liminal rationalism, they significantly capture the evolving patterns of neighbourhood interdependence.

Multiple cycles of migrants' gatherings in public spaces highlighted their predominant critique of municipal leaders and government officials for neglecting requests for social housing upgrade projects. Communal activities—including music, games, laundry, gardening, mechanical repairs and recycling—not only shaped the temporal and social character of these districts but also contributed to political non-hierarchical dynamics. These dynamics signify a diachronic rather than chronological sequence of building and socialisation through political "time-space compression" that calls for "an interrogation of new futures" of informal community organisations (Harvey 2020, 239).

Migrants' building creativity, self-reinvention and community decision-making confirm Lefebvre's "forgotten [and] erased place of architectural work" as design processes that incorporate communities' socio-temporal dynamics (Stanek 2011). Rather than viewing architectural practice as merely an effect and instrument of overwhelming social forces—rejecting the notion that "nothing can be done because of capitalism, which commands and co-opts" (Lefebvre 2014c, 3)—I traced spatiotemporal dynamics to support the philosopher's call for "a dialectical understanding of the conflict between a specifically architectural imagination and the forces aimed at instrumentalising it" (Stanek 2011, 250). This approach advances "the possibility of an architectural imagination beyond the architects' position", achieved through critical engagement with design and research commissions, thus encouraging a rethinking of architectural labour within "the processes of spatial production, and to renegotiate it" (Boano 2015). Ultimately, rhythm analysis enriches the architectural design process through migrants' experiences of dwelling development, transformation of communal spaces and community building renegotiation.

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Titomeniks—Bridging Past and Future
A Socio-Architectural Exploration of Yugoslav Monuments through the Lens of Star´s Boundary Object Theory

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ABSTRACT: The paper aims to highlight the social role of architecture and the associated social responsibility of architects. To this end the study employs a qualitative research approach to investigate the role of Yugoslav memorial architecture from the Tito era, using *Boundary Object Theory* as a framework drawing inspiration from Susan Leigh Star"s sociological framework. *Boundary Objects* are located at the interface between communities and are able to build bridges between conflicting points of view. Driven by the question of how architecture can serve as a medium for engaging with different and potentially contradictory social world perspectives, Boundary Objects connect these divergent views of professionals and stakeholders, providing a common basis for discussion. An interdisciplinary approach allows for a comprehensive examination of historical complexity, the shifts over time and their role in evolving social and political contexts. The aim is to establish a foundation for a cooperative dialogue, providing a meaningful basis for navigating architecture into an uncertain future by integrating it into contemporary societal dynamics.

KEYWORDS: Memorial Architecture, Yugoslavia, Boundary Object Theory, Social Worlds, Interdisciplinarity

INTRODUCTION

The discipline of architecture and spatial design does not mean merely contemplating a finite period; rather, it means dealing with our past, reflecting on it and contextualizing all of that within the present circumstances in order to utilize it for a potential future. This is particularly relevant these days, as our focus shifts—not only backwards—towards wars, refugee flows, ethnic exclusion, and destruction. Different identities with divergent pasts and presents are suddenly compelled to share a convergent future. This social responsibility profoundly impacts multiple realms, prompting a critical examination of the ethical and aesthetic foundations of architecture and its architects. The aforementioned identities often manifest in spatialized collective memory; anchored in the walls of our built environment—particularly in memorial architecture. These facets will be explored through the analysis of specific monuments, namely *Titomeniks.* This case study will apply *Boundary Object Theory*, a concept used in social sciences, as its theoretical framework.

1.0 FUNDAMENTUM

1.1 Titomenik

The term *Titomenik*, as well as a study on the conservation values of these monuments in a diverse society derives from the work "Titomenik - Remembering the Future" (Furbach 2017). *Titomenik* is a portmanteau of *Tito* and *Spomenik* (Serbo-Croatian for *monument*). It refers to a collection of monuments exclusive to the former Yugoslavia, predominantly realized during the Tito era. These monuments do not depict Tito as a person in any way but were rather established under his regime. Phonetically, the suffix *menik* deliberately echoes the word *manic* hinting at the concept of madness. This linguistic choice is influenced by two main factors: Firstly, the exceptional quantity of monuments erected between 1940 and 1980s, and secondly, the lasting impact these monuments continue to have today. This memorial architecture, shaped by a fusion of monumental brutalism and organic naturalness, evokes a singular fascination. An article titled "Spaceships for the Dead" sensationally describes these extraordinary sculptures as "winged eyes, giant flowers, and concrete UFOs" (Franz 2011). (Figures 1,2,3 & Furbach 2017)

This unique visual language also captured international attention; notably through Jan Kempenaers' photographic series "Spomenik: #1-26" (Kempenaers 2010), the exhibition "Toward a Concrete Utopia: Architecture in Yugoslavia, 1948–1980" at *MoMA* in New York (MoMA 2019) as well as through media, as exemplified above. Primarily erected to commemorate Partisan battles or victims of concentration camps, Titomeniks were strategically constructed at these very specific locations. Consequently, they are typically situated in remote areas, deep within forests, almost concealed. Titomeniks—as memorial architecture—were created as monuments rather than being designated as such. Thousands of these monuments, along with their surrounding parks, were erected primarily as political instruments to shape a national identity in Yugoslavia. As such, they "both product and evidence of the socialist state's successful liberalization process" (Vuković 2011, 77). Beyond their political function, the monument-complexes also served as public space for picnics, family outings and school-trips. Titomeniks were—hence their futuristic appearance—signposts to a better future, made possible through the sacrifices of fallen partisans at these

special sites. However, this envisioned future has not become present reality. The socialist system that effectively produced and established this identity-shaping memorial architecture ceased to exist following Tito's death. Today, 34 years after the disintegration of Yugoslavia, this is certainly one of the reasons why many of these monuments have increasingly fallen into ruins, were deliberately destroyed, or fallen victim to robbery of their façades (Figures 4,5,6,9,10 & Furbach 2017). Since then, Titomeniks have been in a state of limbo, as their original political foundation and the corresponding legitimacy have vanished. Their socialist past has been overshadowed by the democratic transformation that followed. The present qualitative case study builds on insights gathered during research trips, where I collected empirical data through observations as well as through discussions with both experts and laypersons. To gauge contemporary attitudes toward Titomeniks in today's successor states, a brief survey was used as an indicator of public opinion (Furbach 2017, 21).

1.2 Pre-Yugoslav Era: The Breeding Ground for Identity Conflicts

Dealing with such deeply rooted concepts of identity, it is necessary not only to look at the turbulent history of recent decades; but also, to understand the deep-rooted diremption within the South Slavic region. As early as in the 7th century, the first political entities were founded; with the Serbs establishing *Raška* in the 9th century (*Raška*) and the Croats forming their own political structures in the 10th century. The Bosnians—until then living in ascetic seclusion—underwent Christianisation, with the Serbs introducing Orthodox and the Croats introducing Catholicism. The state Bosna emerged in the 12th century, exerting little influence, which might correlate with its comparatively subordinated position today. Many events further reinforced this military and cultural division, such as the Ottoman conquest, the *Battle of Kosovo*[1], the 19th century uprisings against Ottoman rule, the First Balkan War, and the *London Treaties*[2]. The assassination of Habsburg Archduke Franz Ferdinand and his wife Sophie by a Bosnian Serb in Sarajevo played a significant role in triggering the First World War. Following the dissolution of Austria-Hungary, *the Kingdom of Serbs, Croats and Slovenes* established in 1918 under *King Peter I* and was renamed the *Kingdom of Yugoslavia* in 1929. Regions and states, shaped over centuries by diverse influences, were now expected to function as a unique entity. These deeply rooted differences led to numerous conflicts, particularly between the western-influenced Croats, who advocated federalism, and the eastern-influenced Serbs, who favored centralism. The political structure of this first Yugoslavia was fragile and, lacking internal political consensus, remained particularly vulnerable—even after 23 years of existence—until its occupation by the German Wehrmacht in 1941. The former Yugoslav territories were divided, leading to various approaches in managing the newly assigned territories. In all cases, however, tradition and national sentiment were suppressed; for example, in German-occupied areas of Slovenia, speaking Slovenian was forbidden. (Furbach 2017, 23-29)

1.3 Tito and the Yugoslavian *Brotherhood and Unity*

During World War Two resistance, in the form of Partisans, emerged from the *CPY (Communist Party of Yugoslavia*) under Josip Broz, better known as *Tito*. The *Democratic Federal Yugoslavia* was established in 1943 as a socialist federation consisting of six equal constituent republics: Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia and Slovenia. Tito's paramount principle and that of Yugoslavia was *Brotherhood and Unity*, a state achievable only through the Partisans and their collective struggle. Hence, the commemoration of the Partisans became a constitutive means of Yugoslav identity. To shape and solidify this collective memory, it was celebrated through numerous rituals, national myths, films and other artistic expressions, as well as through numerous monuments. Tito, as the guardian of *Brotherhood and Unity*, made a significant contribution to the survival of Yugoslavia. The powerful cult surrounding his persona reached its peak shortly after his death, when Yugoslavia lost its most crucial pillar. The country descended into a devastating civil war. (Furbach 2017, 79-81)

> *The common went up in flames and made room for the particular, the search for difference became a battle. (Džihić 2015, 1)*



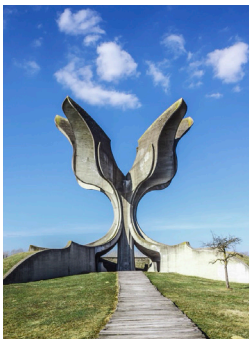




Figure 1 (left): Dušan Džamonja, *Monument to the Revolutionaries*, 1967. Podgarić, Croatia. Source: (Furbach 2017)
Figure 2 (middle): Bogdan Bogdanović, *The Stone Flowe*r, 1966. Jasenovac, Croatia. Source: (Furbach 2017)
Figure 3 (right): Iskra und Jordan Grabul, *Makedonium*, 1974. Kruševo, North Macedonia. Source: (Furbach 2017)

2.0 RATIO

2.1 Inceptum

Considering architecture as a social medium allows both theoretically understanding and empirical analysis of the effectiveness of built space. Societies express their identity through architecture, but they are also, in turn, shaped by it (Delitz 2010, 30). Architecture—both in general and specifically in the context of memorial architecture like Titomeniks—spans a spectrum of disciplines and stakeholders. The communication between these entities can be

hampered in multiple ways. Titomeniks, as embodiments of monumentalized pasts, serve as examples of how architectures can be carried into different futures that seldom align with their original contexts and envisioned ideals of life and future. As past visions of the future transition into the present, the emergence of diverse political, religious, and ethnic perspectives often complicates mutual understanding. This underscores the necessity of following an interdisciplinary approach that not only embraces the plurality of history but also integrates current and transnational discourses. It should actively engage in ongoing discussions surrounding the values and meanings attributed to build space, the dynamics of remembering and forgetting, as well as the intersections with public interests and the imperative that all of this must be continuously redefined. To highlight these diverse perspectives—within a society grappling with the aftermath of recent historical trauma—this paper examines Titomeniks as commemorative architectural objects and considers their role as *Boundary Objects.*

2.2 Susan Leigh Stars "Boundary Objects"

The term *Boundary Object* was introduced by Susan Leigh Star together with James R. Griesemer in their paper "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39" (Star & Griesemer 1989). Star´s work has been multifaceted, making significant interdisciplinary contributions by integrating insights from sociology, science and technology studies, and information science. Her research fosters a holistic understanding of complex sociotechnical systems. She "brought us concepts that traveled through and across disciplines and gave us tools to render often invisible phenomena visible—especially those leading to injustices" (Balka 2010, 647). One of these tools is *Boundary Object Theory* (BOT), in which *Boundary Objects* (BO)[3] serve as an interface between different social groups, enabling cooperation and communication without requiring complete consensus.

> Consensus is not necessary for cooperation nor for the successful conduct of work. This fundamental sociological finding holds in science no less than in any other kind of work. (Star & Griesemer 1989, 388)

The concept of BOT, based on the principle of *Cooperation without Consensus*, raises intriguing questions about how individuals with diverse perspectives and knowledge systems can collaborate, especially in the ever-evolving landscapes of societies and identities. BOT was developed as an alternative to the perspective on objects in Callon´s and Latour´s *Actor-Network Theory* (Callon 1984), which "tends to fix objects in their identity, as 'actants' that" (Garrety & Badham 2000, 4) are either part of the created network or not. In contrast, Star and Griesemer's BOT aims to describe and investigate "situations in which objects accommodate and retain heterogeneous meanings" (Garrety & Badham 2000, 4). Star was a "boundary spanner"; her concept of BOT transcended "disciplinary boundaries and offer substantive theoretical insights to an amazing array of thinkers, representing numerous disciplines" (Balka 2010, 650). Her Theory of *Boundary Objects* has been adapted in various research fields, including sociology, science and technology studies, computer science, and information science. For a deeper understanding of BOT, it is first necessary to examine Star´s and Griesemer´s definition of the term *Boundary Object*: In this context *Boundary* does not imply "something like edge or periphery" (Star 2010, 602), it denotes "a shared space, where exactly that sense of here and there are confounded" (Star 2010, 602-603). These common objects form boundaries "between groups through flexibility and shared structure–they are the stuff of action". The word *Object* is used in "both its computer science and pragmatist senses, as well as in the material sense" (Star 2010, 603), where refers to something people "act toward and with" (Star 2010, 603). The materiality of an object "derives from action, not from a sense of prefabricated stuff or 'thing'-ness" (Star 2010, 603). This implies that theories can be powerful objects. It is crucial to emphasize that Titomeniks are *Boundary Object*s not because of their "thing-ness" but because they are "used between groups in the ways described above" (Star 2010, 603).





Figure 4 (left): Boško Kućanski, *The Poet*, 1978. Makljen, Bosnia-Herzegovina. Source: (Furbach 2017)
Figure 5 (middle): Vuko Bombardelli, *Monument to the first Partisans*, 1961. Košute, Croatia. Source: (Furbach 2017)
Figure 6 (right): Jordan Grabul, *Flower of Freedom*, 1969. Gevgelija, North Macedonia. Source: (Furbach 2017)

2.3 Resulting Social Worlds

The preceding historical review may seem exhaustive, yet it serves as a gateway to diverse perspectives on the Yugoslav past and the present-day South Slavic society. During Tito´s Yugoslavia, Titomeniks conveyed an uncontroversial message—*Unity and Brotherhood*. However, the contemporary significance of these monuments raises more intricate questions about the social worlds they shape today. In the context of *Cooperation without Consensus*, it is crucial to acknowledge that the various actors involved in Titomeniks come from distinct social worlds. A monument conservator responsible for one or more Titomeniks "answers to a different set of audiences and pursues a different set of tasks" (Star & Griesemer 1989, 388) than a former partisan commemorating fallen comrades with flowers at the memorial. Even those who have vandalized Titomeniks, rejecting any association with an unwanted past, belong to different social worlds. "When the worlds of these actors intersect a difficulty appears" (Star & Griesemer 1989, 388). To better understand these dynamics, it is essential to identify some of these social groups engaged with Titomeniks. This analysis draws on my 2017 research trips, field observations conversations,

and small surveys intended as a “mood barometer” (Furbach 2017, 20). The Conceptual Diagram (Figure 7) offers an overview of the various social worlds, complemented by the detailed explanations that follow (this list does not claim to be exhaustive):

° *The Nostalgic* engages with Titomeniks as they were originally intended—as sites of recreation and celebration of Tito's achievements. The powerful Yugoslavian cult surrounding Tito still exists in parts today. The Nostalgic uses the monuments as symbols of past collective achievements. He reminisces about Tito, the former Yugoslavia, *Brotherhood and Unity* or the lost era of communism. (Figures 1,2,3)
° *The Mourner* utilizes Titomeniks in their original capacity. However, in contrast to the Nostalgics, the emphasis here is on the monument as a profound grave site, serving to mourn at the resting place of partisans, victims of concentration camps, or symbolically, the burial ground of Yugoslavia. While there is some initial overlap with the *Nostalgic* in their shared emphasis on remembrance, the Mourner’s engagement is personal and sorrowful.
° *The Political* may resemble the Nostalgic, but with a special inclination toward recalling the era of communism. However, at this point not the *Communist Political* (within this categorization, he is grouped among *The Nostalgics*), but rather the democratic *Political* should be highlighted. For this individual, Titomeniks represent an unpopular political epoch marked by a perceived absence of freedom of expression.
° *The Fascist* also mourns the fallen soldiers but from an opposing perspective. For the Fascist, Titomeniks serve as memorials symbolizing the defeat in the war, viewed through a Greater Serbian, German, Italian, or *Ustaša*[4] lens, making them unloved memorials.
° *The Believer* was largely absent from the public commemorative practice of former Yugoslavia, where religious iconography was not integrated into memorial sites. For this social world, Titomeniks may carry positive connotations, representing an era when religious freedom was officially guaranteed. However, on the contrary, they may also evoke negative associations if the expected meaning of their individual religion was not given their desired recognition. (Fig.8)
° *The Nationalist* perceives Titomeniks as relics of a rejected era of *Brotherhood and Unity*. These monuments symbolize a past time and unity that *the Nationalist* is relieved to have left behind. He supports the independence of the Successor states of Yugoslavia; He may advocate, for instance, for Kosovo’s sovereignty. (Fig.4,5,6,10)
° *The Aficionado* appreciates Titomeniks for their artistic, architectural, or sculptural value: Entangled in the historical and identity conflicts of the South Slavic region, the Aficionado may still harbor a patriotic pride in the artistic products of their homeland (He could also, however, offer an external perspective on the South Slavic Memorials). Potentially an expert in fields such as art history, cultural science, architectural theory or monument conservation, *the Aficionado* aims to document a specific artistic style from an era in a country that no longer exists. This perspective suggests that Titomeniks could be reimagined as essential BOs within the professional cultural community—though this reinterpretation may not necessarily resonate with the broader society.

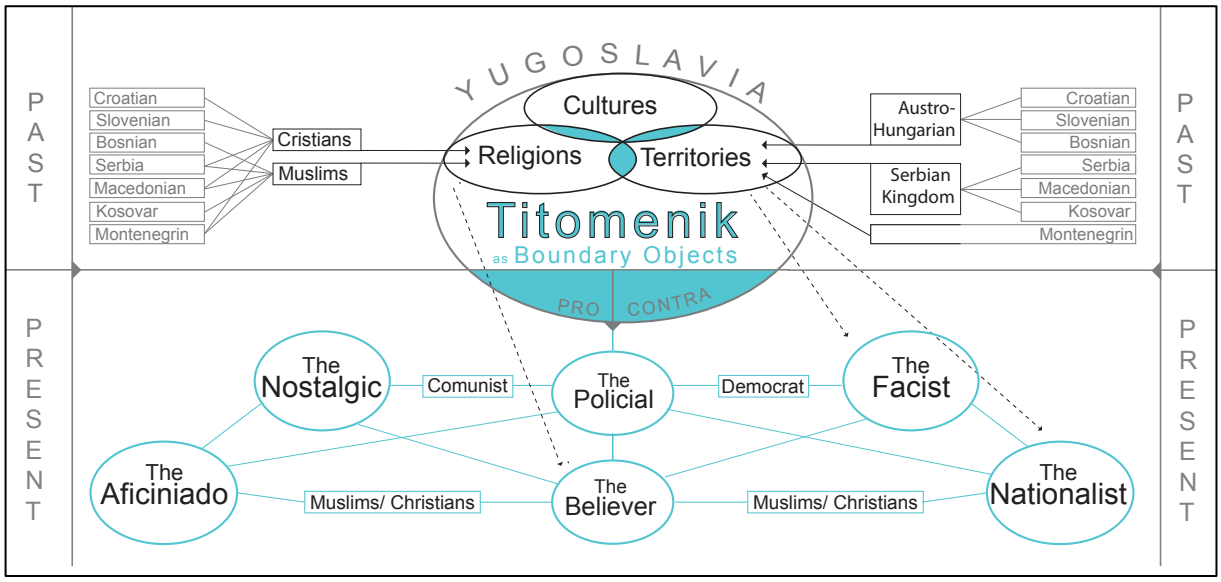


Figure 7: Conceptual Diagram: Social Worlds involved in Titomeniks; today and during Yugoslavia. Source: (Furbach 2017)

It is crucial to recognize that one person can belong to multiple social worlds, and that these affiliations are fluid and ever-changing. “On further investigation, large social worlds usually fragment into smaller ones.” (Garrety & Badham 2000, 3). Listing these exemplary groups serves to clarify the diverse perspectives of populations engaged with Titomeniks. It seeks to explain why different groups of people respond differently to them and how these responses have evolved over time. As BOs, Titomeniks "mean different things in different worlds", which creates challenge for actors attempting to cooperate and reconcile these meanings (Star & Griesemer 1989, 388). This requires significant effort from everyone involved and the "translation" of each perspective (Star & Griesemer 1989, 389).

2.4 Titomeniks as Boundary Objects

A closer examoniation of Star´s and Griesemer´s elucidation of the *Boundary Object Theory* reveals its particular relevance to Yugoslav memorial architecture, “which lives in multiple social worlds and which has different identities

in each" (Star & Griesemer 1989, 409). Therefore, viewing Titomeniks as BOs enables a more comprehensive analysis of the socio-cultural, historical, and political dimension embedded in these monuments. To provide a focused description of BOT in relation to Titomeniks, the terminology and insights of its originator are are used more extensively below. *Boundary Objects* are "both adaptable to different viewpoints and robust enough to maintain identity across them." (Star & Griesemer 1989, 387). Since their construction, Titomeniks have undergone shifts in meaning and changes in how different social worlds engage with them. However, they remain robust enough "to maintain a common identity across sites" (Star & Griesemer 1989, 393); they can serve as the *Common Denominator* that brings together various knowledge bases and communities to achieve a mutual goal (Matilainen 2018, 5). Titomeniks "both inhabit several intersecting social worlds […] satisfy the informational requirements of each of them" (Star & Griesemer 1989, 393), which is particularly clear in the very contrasting interpretations of the social worlds involved around them. But they are nevertheless "plastic enough to adapt to local needs and the constraints of the several parties employing them" (Star & Griesemer 1989, 393). This plasticity is evident in the very different social worlds that have each, in their own way, utilized and continue to utilize Titomeniks as tools. "They are weakly structured in common use and become strongly structured in individual site use" (Star & Griesemer 1989, 393). Titomeniks encompass both abstract and concrete elements. The inscriptions commemorating the fallen or the political speeches that took place at the time of their creation are concrete; the sculptural and artistic forms, on the other hand, are abstract and open to interpretation. Despites "their structure is common enough to more than one world to make them recognizable, a means of translation" (Star & Griesemer 1989, 393); so this structure – common in different social worlds—allows them to be recognized and understood in various environments. Because Titomeniks continue to hold different meanings for various social groups, they offer a framework for exploring these diverse interpretations. This enables a more nuanced and comprehensive analysis of the social impact of monuments, which are "concrete and abstract, specific and general, conventionalized and customized" simultaneously (Star & Griesemer 1989, 408). In the field of political and social theory Garrety and Badham draw a distinction between *Primary* and *Secondary Boundary Object.* A *Primary Boundary Object* may take the form of an artifact "around which all the activity is (supposed to be) focused" (Garrety & Badham 2000, 14)—such as the physical structure of Titomeniks as monuments. *Secondary Boundary Objects* are "subsidiary things that facilitate collective work around the primary object" (Garrety & Badham 2000, 14)—including activities surrounding the artifact, such as the political events or family trips. These events played a role in negotiating the meaning of the monument. In essence, Titomeniks, as artifacts, require contemporary interpretation and social interaction to effectively function as Boundary Objects. The negotiations and knowledge exchange enabled by a BO at a given point in time can evolve even if the object itself does not change (Matilainen 2018, 6). Examining specific monuments within the Titomeniks series reveals distinct states of transformation. Some Titomeniks have evolved from their past role as Boundary Objects, yet they continue to exist. The *Primary BO* remains largely unchanged, while the *Secondary BO* undergoes expansion. One of the most well-known Titomeniks is the *Jasenovac* memorial in Croatia, designed by Bogdan Bogdanović (Figure 2). The Jasenovac camp, initially established in 1941, eventually became one of the largest extermination camps in Europe. After World War II, the concentration camp was dismantled. In response to a request from SUBNOR[5], Bogdanović designed *The Stone Flower* in 1960s, symbolizing life and eternal renewal.







Figure 8 (left): Miodrag Živković & Svetislav Ličina, *Monument to the Braves*, 1969. Ostra, Serbia. Source: (Furbach 2017)
Figure 9 (mid.): Vojin Bakić & Berislav Šerbetić, *Memorial to Resistance*, 1981. Petrova Gora, Croatia. Source: (Furbach 2017)
Figure 10 (right): Vojin Bakić, *Monument to the Liberation*, 1969. Knin, Croatia. Source: (Furbach 2017)

This Titomenik became the centerpiece of this memorial park along the banks of the river *Sava*. Over time, the complex was expanded to include a museum, a library, a publishing house, and spaces for conferences and lectures, making it one of Yugoslavia´s most visited attractions. During the Yugoslav Wars, the entire complex was closed off, because it became unwanted memory (Furbach 2023, 519). This single Titomenik embodies multiple time layers, shaped by different social worlds such as the *Nostalgic* and the *Socialist Political*, which contributed to its preservation—unlike many others that faced desecration or destruction (Fig 4,5,6,10). Commemorative events are still held at the memorial, primarily attracting *The Mourner*, but also finding use by *The Nostalgic* in a similar manner. The additional structures were restored after the Yugoslav Wars and now serve again museal purposes. The *Primary BO*, Bogdanović*´s Stone Flower*, remains unchanged in its form, while the *Secondary BO* (like its exhibition and archive spaces) is restored and expanded in their content. By narrating the history and contextualizing the founding events, space is created for other actors—*Politicians*, *Believers* and *Aficionados*.

The *Memorial for the Brave* in Ostra, Serbia underwent a different form of recontextualization. Located in the solitude of an open field, the Serbian Orthodox Church *St. Petka* was built in 2000 between the memorial and its entrance (Figure 8). Rumors suggest the church was constructed without proper authorization, which may explain

why the building process took 14 years to complete. Unlike the adjacent *Memorial for the Brave*, the Serbian Orthodox Church *St. Petka* remains in excellent condition. (Furbach 2023, 519)

TItomeniks in Košute or Knin (Figures 5, 10) as well as the ones in Makljen or Petrova Gora (Figures 4, 9) and many others exemplify memorial architectures destroyed in the 1990s by unknown perpetrators. Nevertheless, the remnants of these monuments remained on-site decades later (as of 2017, when I visited the monuments). They serve as monuments of extended memory, forming new historical time layers that have the potential to continue involving various actors, positioning the ruinous Titomeniks as a *Boundary Objects.*

CONCLUSION

This study demonstrates that architecture can function as Boundary Objects and investigates how closely its structure is connected to the involved social worlds. The work selects Titomeniks, a specific group of monumental architecture, as a case study to illustrate the application of *Boundary Object Theory* to Architecture. As embodiments of a monumentalized past vision of the future, Titomeniks exemplify here how architecture, in general, extends into actual futures that rarely align with their founding periods and associated visions of life and future. Due to their various states, Titomenics possess the ability to simultaneously represent different layers of time, each belong to contradictory eras and social worlds (Figures 8,10). Acknowledging and understanding the complexity of monumental artifacts through their various layers of time contributes to recognizing antagonistic discourses and perspectives as integralcomponents of their message. This analysis enables to understand how the meaning of architecture evolves since their establishment, especially in response to societal changes, political upheavals, and emerging interpretations. This response is not one-sided; as the chapter on social worlds shows, society also responses to architecture. In a sociological sense, this can create a spatial-theoretical basis for conceptualizing the idea of space as a reciprocal relationship between architecture and society (Hilger 2011, 196). It is therefore hardly expedient to look at what architecture is or what society is in isolation from each other; rather, it should always be analyzed as an interacting structure. The implementation of BOT here reveals that this Architecture-Society-Structure is inherently heterogeneous, contradictory, and that its architecture holds different meanings to different people. Tracing the controversies within the meaning of Titomeniks through social worlds demonstrates that it is not only the architecture that heterogeneity is not limited to the architecture itself but extends equally to the actors and the diverse social worlds surrounding them. These social worlds encompass not only the architects or the original initiators—such as Tito—but also all people surrounding individual Titomeniks.

Titomeniks serve as an illustrative example because, unlike many other memorial architectures, they do not embody specific personalities, featuring only abstract and interpretable forms. This simplifies the identification of common denominators, critical points of agreement, or shared surface references, providing a robust platform for cooperative action. Crucially, this collaboration does not require individuals to relinquish their distinct perspectives, positions, or practices within their respective social worlds. A fundamental prerequisite for this approach is the inclusion of a diverse array of interest groups in an interdisciplinary manner. The *Boundary Object Theory* can then play a crucial role in facilitating social interaction and exchange among diverse groups. In the case of Titomeniks, they offer a unique opportunity to explore social interactions and negotiations among various actors who interpret and assert claims over these monuments. As *Boundary Objects* architectural structures—exemplified through the Titomeniks—can be considered as bridging elements that constantly gather and bring together new and diverse social worlds around them. Negotiating architectural concerns against the backdrop of BOT, the dynamic of social worlds, and interaction between architecture and society, and integrating these into multi-perspective cooperation—whether or not a consensus is achievable—can provide a robust foundation for purposefully guiding architecture into an uncertain future.

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ENDNOTES

1 The Battle of Kosovo in 1389 was a Serbian defeat, but it went down in Serbian history as Vidovdan and is since then celebrated as a victory: Henceforth, pride in the courageous struggle of Christian forces against Muslim dominance became intertwined with Serbian national identity. This patriotism later manifested initially in the commemoration of the Partisans, subsequently reflecting prominently in the pan-Slavic aspirations.
2 In the course of the London Treaties of 1913 the momentous decision was made to incorporate Kosovo into Serbian territory.
3 For the sake of better readability, the abbreviation BOT will be used for Boundary Object Theory and BO for Boundary Object throughout this article.
4 The Ustaša practised a cruel fascist leadership and followed the German model of the "new order" and paid homage to the cult of nation, state and leader".
5 SUBNOR (Savez udruženja boraca narodnooslobodilačkog rata Jugoslavije). English translation: Federation of the Association of Veterans of the National Liberation War of Yugoslavia

Architecture As A Mediator Of Empathy: The Case Of The Orb Pavilion, France

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ABSTRACT: Our study explores the intricate relationship between architectural design, care, and atmospheric experiences at the intersection of architecture and psychology. Focused on understanding how on-site experiences interact with initial design intentions, we delve into specific aspects of architectural care and atmospheres.

In the latter half of the 20th century, the idea of a profound connection between architecture and human well-being gained prominence. Recently, the concept of atmosphere has emphasized the significance of sensory and affective experiences in places, highlighting the empathic link between the body and the built environment. In this article, we investigate how atmosphere studies and empathy illuminate the connections between architectural care design and on-site experiences, using André Bruyère's Orb Pavilion as a case study.

Through analyzing the architect's intentions, conducting architectural and sensory on-site analyses, we aim to demonstrate how a design team's aspirations manifest in the built environment. Our findings underscore the congruence between envisioned aspirations and the on-site experience of the Orb Pavilion, focusing on fostering courtesy, providing supportive care through architecture, and inspiring respect for dignity. We argue that the design team's dispositional empathy can permeate architecture, highlighting the importance of designers cultivating sensitivity to bodily sensations.

KEYWORDS: architectural design, empathy, spatial empathy, care, architectural atmospheres

FOREWORD

This interdisciplinary study spans multiple fields united by a common focus on sensitivity and the human experience. Marie Tesson, an architect and Ph.D. student, explores architecture as a form of care, particularly in postmodern designs aimed at fostering empathy. Angèle Pillot, a clinical psychologist who is non-sighted, investigates the affective dimension of spatial perception in her Ph.D. research. Grounded in phenomenology, her work examines how sound reflection enables the perception of surfaces and voluminous objects.

In this article, we explore integrating our research fields and methodologies to identify design processes and architectural elements that promote care. We outline the theoretical frameworks of our respective disciplines: the evolution of care-focused architecture and the study of sensory and affective experiences in atmospheres. Through a case study, we investigate whether the commented walk method, employed in atmosphere studies (Thibaud, 2022), complements the analysis of architects' intentions and architectural analysis. Specifically, we examine how studying on-site sensory and affective experiences can reveal insights into the effectiveness of design processes and architectural elements in supporting care.

INTRODUCTION

Over the past three decades, there has been a growing interest in the sensory and affective experience of architecture. This interest falls within the field of phenomenology, focusing on the twin concepts of ambiance and atmosphere. According to these concepts, the character of an environment is judged through a complex, multisensory fusion of many factors, rather than solely through visual perception, as is often assumed (Zumthor, 2006).

> An atmospheric perception also involves judgements beyond the five Aristotelian senses, such as sensations of orientation, gravity, balance, stability, motion, duration, continuity, scale and illumination. This complex assessment also includes the dimension of time as experiencing implies duration and the experience fuses perception, memory and imagination (Pallasmaa 2014, 231).

Thus, the characteristics of space are experienced in an embodied, pre-reflective manner, as a diffuse whole rather than in a conscious, precise, and focused way (Pallasmaa 2014).

In recent years, advancements in cognitive sciences and neurosciences have strengthened the psychological and physiological foundations of atmospheres. For instance, Canepa and colleagues (2019) demonstrated that sensitivity to ambient variations is influenced by the perceiver's dispositional empathy; the more empathetic a person is, the greater their emotional response to changes in atmosphere. The concept of an empathic connection to the environment has been part of aesthetic theory since the late nineteenth century (Schutzeichel, 2013).

Spatial empathy describes how the body interacts with and responds to spatial elements, involving an unconscious transfer of emotions into architecture. During this process, individuals experience feelings that seem to originate not from themselves, nor as sensations of the architecture, but as inherent properties of the architecture. These feelings are perceived externally rather than internally (Cazal 2016, 471). Supporting this, Pallasmaa (2014) highlights neurological findings on mirror neurons, which help explain how external physical situations can be internalized.

Atmosphere studies place the individual's sensory and emotional experience at the center of considerations about the built environment. We explore the potential for these studies to address the challenge of designing with well-being in mind. Additionally, the concept of empathy is becoming increasingly pertinent in understanding the body-environment connection. From this perspective, two questions arise: Can the concept of atmosphere inform architectural care practices? If empathy helps us understand the body-environment link, can it also facilitate a connection between architects and users?

To address these questions, we examine a case study of André Bruyère's Orb Pavilion, analyzing the architect's intentions, the architectural elements designed to fulfill these intentions, and the on-site sensory experience.

1. METHOD

1.1 Case study

The work of André Bruyère (1917-1998), a French architect, stands out as a unique embodiment of the emerging postmodern awareness of the critical connection between architecture and human welfare. Firmly convinced that architecture can positively impact the health and well-being of its occupants, Bruyère developed an observational practice grounded in his personal experiences with existing spaces and a keen awareness of others' experiences. Demonstrating a high sensitivity to situations of vulnerability, he endeavors to create spaces he describes as 'tender' (Bruyère 1968) or 'courteous,'[1] meticulously attending to thresholds, intervals, and a diverse range of ambiences and perspectives. His commitment to combatting alienating spaces is evident in various design innovations. Over his extensive career, Bruyère consistently demonstrated inventiveness by proposing diverse spatial organizations that facilitate efficient distribution without the need for corridors (Bruyère 1975).

The Orb Pavilion, situated in Ivry-sur-Seine, was inaugurated in 1991. It responded to a call for end-of-life care proposals initiated by the AP-HP (Public Hospitals of Paris) in 1986. The facility provides care for individuals suffering from various pathologies and disabilities, compounded by advanced age and progressive loss of autonomy. At the inception of the building, the majority of residents are women, with half of them experiencing mental illness. The mortality rate stands at 5% per month. While some retain the ability to walk and talk, others have become unable to communicate or stand. Many will spend the remainder of their lives within the institution, passing away after weeks, months, or even years. They receive care from a dedicated medical and paramedical team.

André Bruyère assembled a diverse team, including a lawyer, a doctor, engineers, a journalist, and a philosopher, to conceive an 86-bed unit at the Hôpital Charles-Foix in Ivry-sur-Seine (cf. Choussat Gille 1988). Distinctive in its detachment from the existing Napoleonic hospital and emancipation from prevailing orthogonality, the design process of the Orb Pavilion was marked by meticulous consideration. Before crafting the space, Bruyère spent a day and a night in the pre-existing ward, identifying spatial dysfunctions. He addressed rectilinear corridors at Charles-Foix, aligning cell doors in an alienating manner. His approach targeted the issues of proximity leading to unpleasant smells and sounds, and the lack of hope emanating from a space deprived of perspectives, exchanges, and links to the outside world (Bruyère 1986).

Building upon these insights and previous architectural contemplations, André Bruyère and his team propose a single-story structure, generously opening onto gardens, and meticulously organized to resemble a forest. The design incorporates passages, clearings, and spaces that vary between protection and exposure, offering a rich spatial experience with diverse ceiling heights, widths, openings, and levels of intimacy. This fluid space is seamlessly interconnected, allowing easy access to various points, while providing secluded areas for tranquility without isolation from crossroads or gathering points. The architectural vision behind the Orb Pavilion aims to amplify the well-being of both patients and caregivers. Bruyère holds a deep conviction that architectural tenderness and consideration, significantly contribute to the experiences of those who frequent the space. Within the architecture of the Orb Pavilion, numerous elements of attention conceived by the architect in his personal living space are evident[2]. Bruyère extends to others the same consideration he applies to himself in his design, creating an environment that reflects his commitment to the well-being and experience of its occupants.





Figure 1: Photo of the Orb Pavilion, showing the garden view toward the refectory from the entrance. The single-story building envelops the garden. Noteworthy features include the concrete veil overhanging from the roof to the terrace. The facades feature numerous windows, from seat height in the bedrooms to full height in the refectory. Source: (Marie Tesson 2022). **Figure 2**: The Orb Pavilion floor plan shows an H-shaped building where every area connects to the garden or a terrace. Instead of corridors, it has a continuous agora that expands and contracts, punctuated by technical boxes. Source: (Marie Tesson 2024)

1.2. Procedure

Our case study adopts an exploratory approach situated at the intersection of disciplines, field methodologies, and sensory realms. We integrated two processes. The first process, spearheaded by *the first author*, manifested as an archives analysis augmented by a spatial analysis. Grounded in archives from the André Bruyère Collection at the Institut Français d'Architecture — particularly the plans, sections, and elevations spanning various project phases — this approach distilled intentional descriptions of the forms and spatial configurations conceived by the architect. The second process, conducted by *the second author*, assumed the form of a multisensory analysis focused on the atmosphere. Leveraging the researcher's nuanced sensory experiences and the foundational principles of atmospheric research, this approach yielded an extraction of situated and dynamic perceptions through a commented walk (Thibaud 2022). These perceptions embraced volume and somaesthetic sensations, encompassing factors such as temperature, air movements, sounds, smells, and textures. For this second process, we have grounded our approach only in one sensory experience, due to the researcher's specific skills: her empirical experience of multisensoriality linked to her blindness, her scientific experience of collecting sensitive phenomenal data, her experience as a body-centred clinical psychologist.

We chose a spontaneous walk, leaving our itinerary undefined. Two constraints guided our exploration: commencing from the entrance hall and covering all spaces. Consequently, we traversed walkways, exterior access points, and common areas, delving into spaces such as the refectory, a bedroom, and a consulting room. The tour spanned an hour. We collected data — comprising observations and sensitive experiences — by documenting our on-site comments.

It should be noted that *the second author* had no information about the data collected by *the first author*. The commented walk was carried out in a naive manner in order to avoid a confirmation's bias.

2. RESULTS

Our approach juxtaposes two distinct analyses. Firstly, *the first author* gathered and analyzed André Bruyère's notes and sketches, identifying three prominent themes: supporting a feeling of courtesy, using spatial design as a supportive form of care medium, and inspiring respect for dignity. Simultaneously, *the second author* analyzed her sensory experience of the Orb Pavilion. This amalgamation forms the basis for comparison with the prevalent themes discerned from the architect's documentation. These results are presented into a discursive form in the following sections.

2.1. Supporting a feeling of curtesy

In his writings, André Bruyère emphasizes the significance he places on architecture as a conduit for interpersonal exchange. It is within this context that he emphasizes the concept of courtesy, which he aims to explore and achieve through architectural design.

From his intentions, we gather that this courtesy is defined by the creation of diverse spaces offering varying degrees of intimacy and communal interaction, and providing a feeling of familiarity as well as the establishment of a spatial rhythm.

For André Bruyère, the concepts of closeness and community can only thrive when there is a profound respect for individual privacy and uniqueness. He contends that architecture can foster this sense of courtesy by offering personal spaces within bedrooms, balanced with shared common areas, and varying degrees of intimacy in between. This design allows for both solitude and collective gatherings. Intimacy unfolds in varying degrees, ensuring that every individual discovers within the edifice and its gardens the sanctuaries that safeguard their dignity and offer solace. The lobby functions as a village square. It provides a glimpse of the patio but tactfully avoids ostentatiously revealing the life within the rooms through its expansive windows. Clear separation from the areas where the bedrooms are distributed is achieved through a bottleneck effect, creating a narrowing passage. Upon passing through, the space unfolds once more. On a sector scale, rooms are clustered around shared walkways and intermediate alcove spaces, offering an added layer of privacy and neighborliness. Residents, with their doors ajar, observe the activity in the communal space.

During the walk, *the second author* perceives spatial variations through feelings of volume. These sensations shift in accordance with the space's dimensions. She articulates a sense of envelopment when the walls draw near to

her body, and a feeling of expansion when the space opens up. These perceptions manifest not only during transitions between distinctly characterized spaces, such as moving from the first hall to a corridor, but also with each step taken, as a result of the continuous undulation of walls and ceiling. The first phenomenon engenders a "sense of intimacy" within small spaces, articulated with precision. For instance, *the second author*, while pointing out a corner within a small clearance, expressed, "I would sit here to rest in this corner." Though unaware of the presence of an armchair beneath a window at that precise spot, her distinctive feelings resonated with a sense of intimacy—a feeling of security conducive to relaxation. A similar experience unfolded during the transition between a corridor, a single room, and an attached bathroom. Each threshold was marked by a notable contrast in the perception of volume, leading to a gradual transition into smaller spaces, correlated with an increasingly profound sense of intimacy. Consequently, throughout the walk, the perception of varying degrees of intimacy is deeply rooted in fluctuations in the sensation of volume.

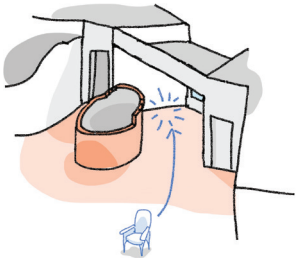




Figure 3: Perspective view of a furnished alcove in the Orb Pavilion. Positioned between two rooms, it has a lower ceiling and is concealed by a mid-height wall, bordering a central storage area. Source: (Marie Tesson 2024). **Figure 4**: Perspective view of a double bedroom in the Orb Pavilion, with each bed having its own space, garden window, seating area, furniture, adjacent door, and seating nook. The room features warm wallpaper and carpeting. Source: (Marie Tesson 2024)

For André Bruyère, establishing courtesy through intimacy requires the space to provide a feeling of familiarity, enabling individuals to find themselves, their place, and to gather. "Intimacy means having your own window, a corner with a comfortable seat, a shelf, a closet that can be opened from the bedroom as well as from the bathroom" (Bruyère n.d.-1, 47). Familiarity must be established by stimulating different senses. For instance, familiar smells, such as those from a fireplace, kitchen, or plants, should be dispersed throughout the building and garden. Every space is decorated in a home-like style, rather than a hospital style. In addition to the original four double rooms, the Orb now offers single rooms and showers resulting from the subdivision of existing rooms and shower facilities[3]. Initially, each room featured dual doors flanking the shower room, delineating distinct thresholds. Placed in front of each door, a stool invited individuals to sit on the doorstep, adding a unique sense of personalization. Every bed also had its designated window, allowing each patient to establish a personalized connection with the outside world. Adjacent to each window was an alcove perfectly sized to accommodate a slightly angled armchair, providing a private haven for everyone. The design ensured that even in double rooms, a high level of intimacy was maintained, thanks to the thoughtful attention given to door and window spaces. Conversely, certain areas are dedicated to fostering conditions for communal interactions. This includes the tea area, which doubles as the TV space, and the refectory. The latter stands as the sole space purposefully designed to accommodate and unite all patients and caregivers. No other space within the department achieves such a comprehensive scale, endowing the refectory with the status of a genuine foyer in this collective dwelling. Other communal areas organize groups and interpersonal relationships on smaller, more intimate/familiar scales.

During the journey, the sense of familiarity was evoked through the meaningfulness of the sensations experienced. Sounds and smells were directly recognizable and understandable, requiring no particular attention to be identified. Furthermore, there was coherence between the perceived dimensions of a space and its intended use, relative to the expectations of the second author. Common areas had larger spaces, while personal spaces offered smaller ones. This coherence also contributed to the comprehensibility of the sensations.

André Bruyère also considers rhythm in his designs. Courtesy is possible if there is a chance to get confused, to feel that the space is unpredictable, to discover different areas of the building gradually, and to recognize particular features over time. He envisions the building with a jazzy rhythm, characterized by variations in repetition and multiple intertwined stimulations.

During the walk, *the second author* articulates a sense of expansion when the space opens up. This phenomenon, intertwined with the curves of the building, is characterized by a sense of communion with the architecture. Feelings of volume undergoes continuous shifts, influencing impressions in brief moments. It appears that the architectural atmosphere harmonizes with the natural rhythm of breath and the sway of steps. These ever-changing sensations forge a localized bond between the individual and the building, sparking arousal rather than sensory monotony. A similar sense of rhythm, mediated by sensory contrasts, occurred with the presence of loudspeakers broadcasting music. Their thoughtfully scattered arrangement gives rise to nuanced fluctuations in sound intensity, ensuring that the walking space remains non-uniform throughout. This deliberate setup creates diverse soundscapes, ranging from quieter areas to more musical zones and intermediate spaces.



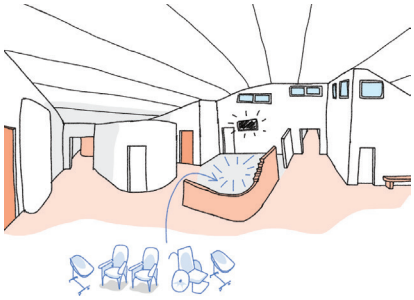
Figure 5: Floor plan of the Orb Pavilion walkways, marking red speaker points and green scent diffusers observed during our walkthrough. Some may have been overlooked. Source: (Marie Tesson 2024)

2.2. Using spatial design as a supportive form of care

André Bruyère is persuaded that architecture can play a significant role in patients' well-being. He even claims that the Orb Pavilion serves as proof of this hypothesis (Bruyère 1993(2), 5; n.d.(1), 4). We have grouped all the measures aimed at enhancing mental and physical well-being in this section. These principles are designed to influence the mind, fostering a positive and/or restorative state of mind.

André Bruyère hypothesizes that architectural uniformity isolates individuals and stifles the expression of their unique identities. To embrace diversity, spaces must abound with variety. He emphasizes the necessity of eschewing repetition and embracing imperfections, accidents, randomness, and subtleties. An inhabitable place, according to him, thrives on deliberate ambiguity. "To construct effectively, one must conceive every individual trait" (Bruyère 1976, 72). Consequently, each place becomes recognizable, facilitating orientation and personal connection, due to its distinctive shape, materiality, and sequencing.

To achieve this goal, he designs a continuous, undulating space that maintains a sense of continuity while avoiding repetition. Distinctions are made through various elements such as window position, orientation, size, and views; ceiling height; width of pathways; perspectives; materials (including bricks, concrete, plaster, marble, and carpet); color variations (including white, ochre and orange tones); temperatures; luminosity; smells; and music intensity. For instance, both the tea area and the refectory boast lofty ceilings and are centrally positioned, intersecting the walkways, yet they exhibit distinct characteristics. The TV area is demarcated from the pedestrian zone by a variably heighted low wall, featuring concealed corners and others open to curiosity. Its layout creates doorways of varying formality and offers no direct sightline to the exterior, relying on high openings for natural light. It echoes the spatial design of the now-unused fireplace area, adjacent to the former private kitchen. On the other hand, the refectory is predominantly glazed, opening onto the terrace, partially shielded by a cascading concrete veil from roof to ground. Positioned at the central bar of the H-shaped Orb plan, it serves as a spacious agora overseen by the care areas. This area is the brightest and most prominently visible within the building. During the conception of the Orb, the walls of the rooms are adorned with wallpapers of assorted hues (blue, mauve, turquoise, pink) and patterns reminiscent of grandmother-style designs; the room doors feature diverse shades of varnish and various oculus shapes, complemented by distinct curtains. In communal areas, each space boasts a unique acoustic profile crafted to instill a sense of calm. Diversity permeates every aspect as one traverses through the premises.



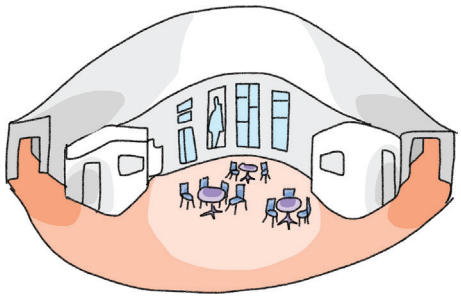


Figure 6: Perspective view of the architectural layout of the tea area, characterized by generous dimensions with high ceilings and ample width. It is defined by a low wall that ascends from chest height to human height. Source: (Marie Tesson 2024). **Figure 7**: Perspective view of the refectory space, tapered at each end and characterized by a substantial central volume. The area, enhanced by lofty windows, extends its reach to the garden and an adjoining terrace. Source: (Marie Tesson 2024)

Throughout the walk, *the second author* observed several multisensory feelings that collectively imparted a sense of being immersed in or near nature. Indeed, in certain areas, distinct scents prevail, with some spaces characterized by a strong aroma of citrus, while others exude the refreshing fragrance of eucalyptus. The intensity of these olfactory experiences varies depending on proximity to a diffuser, resulting in a nuanced sensory journey dictated by our location. Additionally, she observed a particular movement of breeze in the entrance hall, prompting spontaneous reflections on the sensation of transition: "Here, you know that you are between indoor and outdoor," she remarked. "It feels like the breeze is guiding you toward the corridor's entrance," likening it to the sensation of being in a veranda. Furthermore, in this same location, the sound of running water could be heard when the fountain's taps were opened. Moreover, *the second author* elaborated on how the curves of the building create the sensation of traversing a forest path, flanked by trees. In a forest, the diffusion of sound is irregularly shaped by the random placement and contours of vegetation. Similarly, the resonance within the corridors, experienced with each step, mirrors this chaotic arrangement. This sensory experience is especially pronounced in walking areas such as corridors, endowing them with a distinct identity tied to motion. She also emphasizes how smells, music, and contrasts in volume contribute to the creation of distinct spatialities. Within these spatial realms, the boundaries can

sometimes blur, with gradual transitions, as observed with smells. Conversely, in certain instances, the thresholds are more pronounced, particularly evident in variations in volume, such as the transition from the refectory to the corridor or from the corridor to alcoves.



Figure 8: Perspective view of the circular bench in the Orb Pavilion lobby, emphasizing key sensory elements: basin, fragrances, speakers, air currents, light, and garden view. Source: (Marie Tesson 2024). **Figure 9**: Perspective view of the fireplace area shows the undulating ceiling and various passageways. Source: (Marie Tesson 2024). **Figure 10**: Photo of the fluid space. The gloss of the plastic flooring disrupts spatial perception. The colored paint strokes are vibrant yet cool. Source: (Marie Tesson 2024)

Throughout her exploration of the Orb Pavilion, *the second author* highlighted instances of localized material simplicity. Interestingly, during the 2014 renovation at various points, materiality was streamlined by opting for smooth surfaces (plasterboard-type) instead of the original ochre brick cladding, resulting in a compound impoverishment — loss of color, texture, inertia, and resonance. On the flooring, the original dark, subtly soft nylon carpet has been substituted with a sleek, glossy grey plastic covering. This replacement is not only visually displeasing but also less comfortable and reassuring to the touch, especially considering the carpet's initial ability to provide a cushioning effect in case of falls. The bedroom doors, each originally adorned with a distinct porthole, underwent a transformation, replaced by featureless doors with no details or openings. Furthermore, the entire space underwent a repaint in white and grey, leading to the need for additional signage to guide visitors.

2.3. Inspiring respect for dignity

André Bruyère emphasizes that the pavilion should be a living space rather than just a place for treatment. Each individual should be considered primarily as an individual, with their illness or disability not defining them. This principle extends to the architectural design of a geriatric service within a hospital. To ensure dignity for everyone, whether patient or caregiver, the space must continue to serve goals, freedom, and a sense of novelty. These are essential elements for prioritizing life itself.

The floor plan of the building is meticulously designed so that each section is distinct, avoiding any sense of genericity. Paths within the building lead to open endings that provide views of the garden, alcoves for relaxation, and exits for fresh air. Each pathway is unique, turning walking into a purposeful activity rather than aimless wandering. André Bruyère, himself a former resistance member and supporter of the May 68 movement, prioritizes individual freedom through his architectural approach. He strives to keep both body and mind as liberated as possible by creating spaces that embrace diversity, resist repetition, and avoid dead-ends. To achieve this, he uses strangeness as a tool to continually surprise and challenge occupants, encouraging active engagement with their surroundings.



Figure 11: Floor plan of the Orb Pavilion walkways, highlighting viewpoints, direct exterior access (arrows), areas of constriction (dark), and expansion (light). Spatial dynamics continuously transform through interplays of openings, lighting variations, and bottlenecks. Source: (Marie Tesson 2024). **Figure 12**: Perspective view of an alcove in the Orb Pavilion, furnished and nestled within undulating walls, creating a secluded environment where the walkway contracts, marking the culmination of the building. Source: (Marie Tesson 2024)

During the walk, the second author emphasizes the building's relationship with its exterior. In the hall, the airy movement of the constant breeze suggests a transition between inside and outside. As one walks, the shrinking volumes of the walkways indicate approaching a door that leads outside, creating the impression that the building guides us toward exterior spaces. The sense of volume created by the continuous curves of the walkways contrasts with the sensory monotony of a straight corridor. This unusual spatial organization engages the body in the present moment, compelling it to experience these sensations locally and fostering a sense of empowerment.

3. DISCUSSION

The primary objective of this study was to explore whether the concept of atmospheres can inform architectural care practices. We hypothesize that, firstly, the concept of atmosphere can provide valuable insights into architectural care practices, and secondly, that the concept of empathy can help establish a connection between architects and users. To support our hypotheses, we present a case study investigating the relationship between the architect's intentions in designing the Orb Pavilion in France and the sensory experiences it offers to its users.

Initially, we observe that many of the architect's intentions resonate within the sensory experience of the building. According to Griffero (2020), one of the atmospheric thinkers, resonance arises from our innate predisposition to be affected by the external world. It occurs through the immediate evocation of initial impressions that shape our spatial experiences by interacting with the affective affordances embedded in the environment.

In our study, the building resonates with our physicality. For instance, the continuous curves defining the walls and ceilings synchronize with our internal rhythms; one may notice their breathing and swaying coinciding with the variations of hollows and bumps that surround them. As Raphaëlle Cazal writes in her text "Habiter":

> It is a question of working towards a renewal of perceptions, which is made possible, for example, by fluid walking spaces: these spaces induce more pronounced visual distortions than rectilinear spaces and also provide hidden zones at turns that we are encouraged to discover, unlike the former where everything to be seen is given to us at once. The variety of views can also be enhanced by the spatial rhythm created by windows, which, as we move, provide us with unpredictable and changing views of the outside. (Cazal 2014, 62)

It's intriguing to observe that some of the intentions implemented in the design process of the Orb Pavilion have a sensitive resonance, likely not anticipated. These same curves, crafted with the intention of courtesy, evoke not only visual experiences but also resonate with feelings of acoustic volume. It's noteworthy that these sensations of volume exist in sighted people at a pre-reflective level (Pillot et al. 2024), suggesting that they unconsciously influence our perception of spaces.

It becomes evident that this resonance is cultivated through a deliberately multisensory aesthetic. This characteristic appears to cultivate a sense of enduring connection throughout the journey, or in simpler terms, an ongoing resonance with the building. The spatial and sensory richness of the Orb Pavilion offers a plethora of atmospheric elements that facilitate resonance between the user and the building. This perspective resonates with the concept of spatial empathy: there exists a connection between the individual immersed in an environment and the qualities inherent to that environment. The concept of empathy helps operationalize the link between an individual and the atmospheric characteristics of a place, characterizing this connection without presupposing its affective valence - it can evoke either positive or negative emotional responses. For instance, the lack of material variety in the Orb Pavilion produced a negative feeling in the second author's experience. Furthermore, if users' empathy influences the intensity of their experiences in places, as Canepa and colleagues (2019) have shown, it raises the question of the architect's empathy in the design process.

A building is the culmination of a creative process involving the psychological and cognitive efforts of the design team. It stands at the intersection of two dynamics: the transfer of the design team's intentions into the design process, and the translation of atmospheric characteristics inherent in design choices into the sensory experience of users. This perspective raises questions about the empathic skills required by designers to anticipate the atmospheric effects of their creations. Thus, we explore the possibility that architecture can mediate the empathy imparted to users during the design stage. In other words, we propose that the sensory experience of a building may reflect the empathy instilled by the architect during its design.

What is remarkable in the case of the Orb Pavilion, is the architect's empathy in comprehending the context and specific vulnerabilities of the building's users and, also, his adeptness in translating this empathy into the fabric of his architecture. His mastery in this regard turns his architectural creations into conduits of his own empathetic understanding. Two pivotal elements define this process: experimentation and observation. André Bruyère dedicated himself to the architect's quest for empathetic features, refining certain elements throughout his extensive career. For instance, his deliberate absence of corridors and emphasis on connecting private rooms with common areas showcase his commitment to fostering connections among inhabitants.

It should be notice that André Bruyère composed a multidisciplinary design team, including the influence of his daughter Isabelle Baladier, a clinical psychologist. It contributed to this reciprocal interplay of ideas.

CONCLUSION

In conclusion, we propose that studying in-situ atmospheres by collecting sensory and affective experiences can complement architectural practice analysis. This approach can highlight relevant design choices and promote architectural care as an empathetic practice.

We posit that architecture serves as a mediator of dispositional empathy between design teams and users. While empathy is crucial for architects to envision the realities of future users, addressing their needs should extend beyond mere functionality to encompass psychological well-being and the aesthetics of care. Although empathy is undoubtedly a pivotal quality fostering a caring approach in architecture, it may not be the sole determinant. Recognizing, at a personal level, the aspects of the environment that enhance well-being and empowerment is essential in translating them into a design project. This ability appears to derive from a predisposition to introspection and the observation of constructed situations and their impact. Additionally, an interest in the underlying frameworks

of thought that drive emotional resonance and care, whether through direct knowledge or interdisciplinary perspectives, can further facilitate the empathic diffusion.

ACKNOWLEDGEMENTS

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ENDNOTES

1 André Bruyère, “Notes”, probably preliminary notes to Pourquoi des Architectes, (unpublished, Fonds d’archives André Bruyère de l’Ifa, n.d. [1968 ?]), 17.

2 Les Eyrascles house, built in 1970 in Maussane-les-Alpilles in southern France by André Bruyère for himself and his partner Boba. Similar spatial features can be found in the common areas, with the ceiling of the living room evoking that of the Orb refectory, the flat basin in the entrance hall and the work around the fireplace, to name but a few examples. Similar details are also present in the apartment he adapted for Michel Piccoli in Paris's 6th arrondissement in 1965 (notably the circular bench).

3 When work was carried out in 2014, patients expressed the desire to have single rooms. After the renovations, many regretted their choice.

Unveiling Transformative Urban Dynamics: The Symbiosis of Squatting Movement and Urban Renewal in Copenhagen's Architectural Landscape

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ABSTRACT: This study explores the dynamic interplay between Copenhagen's squatting movement and urban renewal, with particular emphasis on public spaces. Drawing on architectural ethnography and historical analysis—anchored by Henri Lefebvre's concept of the right to the city—it traces the movement's evolution from addressing the 1960s housing crisis to confronting contemporary challenges. The research highlights the movement's adaptability, strategic engagement, and significant contributions to urban spatial distribution. The squatter movement emerges as both a force of resistance and a political actor, illustrating how squatters evolved from disruptors to influential participants. A historical comparison underscores urban renewal's critical impact on the squatting movement, while an in-depth case study of Folkets Hus demonstrates a tangible symbiosis between grassroots activism and municipal development. Navigating tensions around gentrification, legal frameworks, and socioeconomic shifts, the paper identifies opportunities for resilience and collaboration—ultimately envisioning a more inclusive, democratic, and sustainable urban future for Copenhagen.

KEYWORDS: squatting movement, urban renewal, Copenhagen, right to the city, architectural ethnography.

INTRODUCTION

This Study delves into the intricate relationship between the public space, the squatting movement in Copenhagen, urban renewal, and the assertion of the right to the city. The squatter movement still received particular attention in the academic arena, especially in sociology and political science. Rene Karpantschof, a former member of the Squatter movement, had a series of research on the squatter movement in Denmark. His Study is from radicalisation (Karpantschof 2015) and social control (Mikkelsen and Karpantschof 2001) construct a general context (*The City Is Ours* 2014). Martinez's studies revealed the ideology (M. A. Martínez and Polanska 2020) and societal acceptance (M. Martínez 2019) side of squatters. On the architecture side, the Netherlands, England, Sweden, Germany, and Finland are starting to pay attention to this topic, from utopia(Delgado 2012), spatial practice(Boer, Verzier, and Truijen 2019), urban space to its link with cohousing (Vasudevan 2015b).

In Copenhagen, squatting evolved from addressing an acute housing crisis in the 1960s to strategically engaging with urban renewal initiatives in later decades. This paper situates the squatter movement within the framework of Lefebvre's right to the city—an inclusive, democratic vision in which citizens actively shape urban spaces. By analyzing historical patterns and a specific case (Folkets Hus), it demonstrates how squatters contributed to dynamic changes in Copenhagen's built environment, becoming a crucial part of the city's political and spatial discourse.

1.0 ON SQUATTING AS A TRANSFORMATIVE SPATIAL PRACTICE

1.1.The right to the city and squatting movement

> *"The word's squatters' give some reality to Henri Lefebvre's loose concept of the right to the city. 'they are excluded, so they take."* (Neuwirth 2006)

Henri Lefebvre, a French Marxist philosopher, introduced the concept of the right to the city in his book, Le Droit à la Ville (The Right to the City), published in 1968. Lefebvre argued that the right to the city is not merely about having access to urban amenities but also about having the power to shape the city in a way that meets the needs of all its inhabitants. He believed that cities should be places where people can live, work, and play in a way that is sustainable, equitable, and democratic. (Lefebvre et al. 1997). David Harvey, an American geographer and political theorist, has built upon Lefebvre's work on the right to the city, arguing that it is a right to participate in the production of space. Harvey believes cities are not static entities but are constantly being produced through the actions of individuals, groups, and institutions. He argues that the right to the city is a right to shape this production process, ensuring that it meets the needs of all city dwellers. (Harvey 2008)

Urban squatting in the global north is the practice of occupying abandoned or unoccupied buildings without permission from the legal owner. There are often residential squats and political squatting movements('Squatting' 2023). Squatters typically reside in abandoned buildings and sometimes make necessary repairs to the property to make it livable. (Vasudevan 2023)

The relationship between squatting in the global north and the right to the city is complex and multifaceted. On the one hand, squatting can be seen as a direct manifestation of the right to the city, as it allows individuals to take control of urban spaces and use them in ways that meet their needs. Squatters often transform these spaces into vibrant hubs of community life, providing affordable housing, cultural centres, and spaces for social and political gatherings. (Vasudevan 2015a). The squatting movement is a testament to the enduring relevance of Lefebvre's and Harvey's concept of the right to the city.

In particular in the public space, squatting is a practice of the right to the city that squatters have when redefining urban places for social needs and cultural resistance. They remind us that cities do not stand still but are constructed as dynamic landscapes through collective power and a commitment to the right of the city for all. At the same time, it is a challenge to the authorities since they interfere in the process of urban renewal development. In this paper, as we take the first steps in this exploration, the right to the city will be our guiding theoretical cornerstone in understanding how squatting is transformed into a force that sculpts physical and socio-political landscapes in the pulsating urban climate of Copenhagen.

1.2. Squatting movement in copenhagen: a dynamic chronology

Copenhagen, somehow represented by iconic places like Christiania, floating buildings in FredensHavn, the youth house (Ungdomshuset), and the Folkets Hus, stands testament to squatting as a radical and accessible spatial practice, played a significant role in shaping Copenhagen's urban landscape and challenging the established norms of urban development. Jacob Ludvigsen, a key figure in Christiania's inception, called it a framework for "an alternative city" (Ludvigsen 2003).

Squatting in Copenhagen has evolved over the years, mirroring the city's changing social and political landscape. Its roots trace back to the 1960s, when it emerged as a response to the housing crisis, providing affordable accommodation for youth and students. This initial wave sparked the proliferation of squats throughout the city and its surroundings. (*DR* 2019)

The period of 1970s-1980s followed with the second wave of squatting inspired by the counterculture movement, followed by student protests against the Vietnam War. Young dissidents in a search for alternative living spaces and as an integral part of their resistance to mainstream societal norms moved in the abandoned buildings all over the inner-city neighborhoods such as Nørrebro and Vesterbro. This period actually hailed the establishment of Christiania – a free state that lives on even now.

From the 1990s on, squatting was focused on the most urgent social and political issues: refugee and immigrant rights and battling gentrification. This wave produced projects dedicated to the struggle against those pressing concerns as well, providing additional proof of the adaptability and versatility of the squatting movement.

The latest wave, from the 2000s until today, is typified by its high fragmentation and decentralization. Squatters focus on creating alternative social and cultural spaces, often using confrontational tactics to reclaim them. (*The City Is Ours : Squatting and Autonomous Movements in Europe from the 1970s to the Present /* 2014) Squatter spaces, acting as transformative forces, challenge the traditional power structures in urban spaces. Danish squatters have skillfully balanced democratic procedures, dissent, and participatory democracy, maintaining a spatial-political network and a critical voice. Their spatial legacy lies in transforming vacant premises, reusing construction materials, and creating collective live-work spaces at both building and neighbourhood levels, showcasing the mediation between vacancy ownership and the right to housing(Vasudevan 2015a).

1.3. Squatting in Copenhagen's urban space.

Traditionally, in the squatting movement in Copenhagen, the Nørrebro district, known for its working-class and immigrant communities(Loveless 2019), has been the main battleground. However, at the movement's inception, Christianshavn became a frontline due to a municipal redevelopment plan targeting its abundance of 18th-century buildings slated for demolition. Faced with a housing shortage and propelled by coincidences and the municipal redevelopment plan(*DR* 2019), Christianshavn became the outpost of the squatting movement. After being wholly evicted around 1970, they established a new base in the Bådsmandsstræde Barrack within the same district, later known as the Christiania area.

The movement's expansion to Nørrebro and Vesterbro further underscores its ability to navigate and influence changing urban landscapes. This shift speaks to the movement's resilience and suggests a deliberate effort to engage with different socioeconomic contexts and demographics. The strategic expansion positions the squatting movement as not merely reactive but as an active and politically conscious force (Mikkelsen and Karpantschof 2001), shaping its trajectory based on the evolving dynamics of Copenhagen's urban development.

Based on available information from the BZ website, I have mapped out the approximate spatial distribution of squatting points in Copenhagen on a map (Figure 1). Mapping squatting points in Copenhagen provides a visual representation of the movement's spatial distribution, offering insights into its geographical evolution over time.

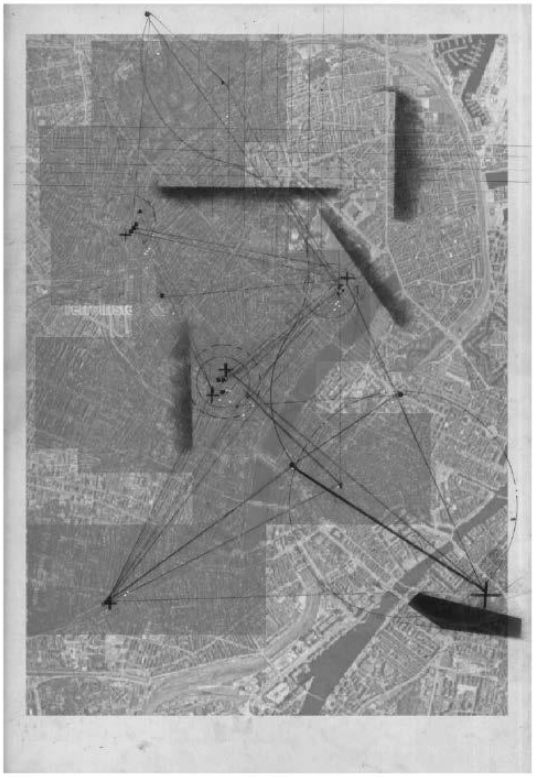


Figure 1: Mapping of squatter movement history. Source: (Author 2023, source: bzportalen.dk/)

The strategic choices made by squatters in Copenhagen, particularly in neighbourhoods such as Nørrebro, Christianshavn, and Vesterbro, go beyond mere spatial occupation; they embody a form of urban activism that challenges established urban development plans and addresses housing shortages. The selection of Nørrebro reflects a deliberate engagement with social issues, targeting a region with housing shortages and a marginalised demographic. The center stage of Christianshavn acts as a site of resistance against municipal development that claims the right to the preservation of historic urban fabric in the face of gentrification pressures. The spread into Vesterbro provides an example of adaptability that positions squatters as active agents in changing urban dynamics. The spatial choices symbolically challenge authority, disrupt conventional urban renewal processes, and mediate between vacancy ownership and the fundamental right to housing. Squatters' strategic spatial choices in Copenhagen result in an active, inclusive and dynamic urban spatial distribution, advancing an urban activism that is actively working towards the forming of the city in finding solutions to pressing issues of a complex society.

1.4 Conclusion

Copenhagen's squatting movement exemplifies a transformative spatial practice anchored in the right to the city. From addressing the 1960s housing crisis to contending with 21st-century challenges, squatters have repeatedly adapted, negotiated, and contested authority. Their influence ranges from neighborhood-based interventions to broader municipal dialogues, emphasizing how grassroots practices can foster more democratic, equitable, and sustainable urban environments.

2.0 UNRAVELING THE DYNAMICS: SQUATTER MOVEMENT AND URBAN RENEWAL IN COPENHAGEN'S URBAN LANDSCAPE

2.1. Squatter movement and urban renewal dynamics

The interaction of the squatter movement with urban renewal in Copenhagen reveals a far more nuanced story of resistance and collaboration. Once seen as nothing but destructive elements, squatters even began to make strategic decisions to occupy buildings on purpose in the "interim period" of urban development plans. The tactical maneuvering—squatting houses along the path to demolition—exemplified, in public, the way in which they could turn potential wastelands into vibrant, occupied space.

Where squatters had been passive victims of urban development, by the time the movement matured, they became active political agents in this process. Far from simply bypassing the city government, their newfound means of organizing and occupying space strategically would come to be repurposed as a valuable resource for future planning efforts. The strange dual paradoxical role that the squatters played—challenging but also contributing to the plans of the city—is quite suggestive of the complex dynamics built into the relationship between grassroots movements and efforts within municipal governments toward urban development. Squatting was a powerful means for the community to reclaim space and resist imposed city structures.

Overtaking buildings destined for demolition, squatters had the ability to fill them with life, turning empty shells into living cultural centers, alternative dwellings, and centers of political protest. The resulting BZ-lejligheder (BZ flats) came to symbolize resistance against established power, and as the active sculpting of the urban environment

itself. It demonstrates a change in the squatters from being disruptors to being political influencers, showing that their strategic actions contested not just the prevailing redevelopment plans but also, although inadvertently, resulted in a positive change for the evolving cityscape. This shows how their effects on Copenhagen's urban renewal were multifaceted.

2.2. A rapid potted historical comparison: squatting movement and urban renewal in Copenhagen

Table 1. Source: (AF RIKKE CAROLINE 2016; 'Sådan Er København Fornyet' 2003)

TIME	SQUATTER MOVEMENT	URBAN RENEWAL
The 1950S		The first urban renewal in Copenhagen was completed. Adelgade and Borgergade were redeveloped according to the Redevelopment Act of 1939
The 1960S	*February 1963*: The first occupation is carried out by 'Group 61.' *May 1965:* Sofiegården an action that will last almost four years *Summer 1966*: A nod from the Lord Mayor *February 1969*: proclaim their home to the 'Republic of Sofiegården', *27 February 1969*, the police moved in	Parts of the oldest residential buildings in Vesterbro and Nørrebro were demolished, and renovations began on Christianshavn.
The 1970S	1970: House occupations intensified, activists were dubbed "slum storms." 1971: Christiania was born. ; Folkets Park' in Nørrebro is established; the Folketing introduced "slum storm clause", 1973 Nørrebro Beboeraktion formed	The demolition of the oldest and most worn housing construction in Vesterbro and Nørrebro continued and the redevelopment of Christianshavn.
The 1980S	Spring 1980: The Battle of the Byggeren 1981: Police throw tear gas at BZs, 1982: The BZs get a youth center, Jagtvej 69,Ungdomshuset. 1983: The BZs make fun of the police 1986: The Battle of Ryesgade Later, in the 80s, the movement also targeted foreign political issues.	Now, urban renewal has taken off. Decades are marked by massive demolition, restoration and reconstruction according to 1939, 1959 and 1969 redevelopment laws. Among other things. The entire black square in Nørrebro and the entire Gammelholm district. For example. Havnegade, Peder Skrams Gade and Olfert Fischers Gade.
The 1990S	1993: For the first time since World War II, officers shoot into protesters directly in an EU vote. In 1994-95, the BZ movement disintegrated and continued as 'the autonomous'.	Urban renewal began under the Urban Renewal Act in 1983, and 40 per cent. Of all, money was used for the action plan in inner Vesterbro. The rest was used to renovate 22 squares scattered throughout the city except Vanløse. In the 1990s, the Danish Medical Association's Housing, also called Brumleby, was modernised. The redevelopment of Brumleby is one of the most talked-about and costs about half a billion. KR.
The 2000S	2007: The police clear the Youth House, 714 people are arrested. 2009: Illegal Mass Arrests In the run-up to the COP 15 climate summit Parts of the BZ movement have been carried on by the 'autonomous'.	The large, concentrated entire neighbourhoods are now over, and the future urban renewal will occur more widely. In recent years, the City of Copenhagen's investments in urban renewal have been around half a billion. DKK annually, and since 1983, almost 18,000 homes have been urban renewed

The historical comparison in Table 1 illustrates a dynamic and closely interrelated correlation between urban renewal and the squatter movement in Copenhagen. There is support for the existence of a negative correlation between the thoroughness of renewal and the vitality of the squatter movement; that is, extensive efforts at renewal help to dampen the otherwise vibrant movement. The other way around is not always the case, which in itself only illustrates the entangled and complex relationship of urban renewal moves and the squatter movement. It foregrounds, therefore, the importance of urban renewal in the vitality and survival space of the squatter movement.

The impact of urban renewal interventions, specifically on transformed public spaces and normativity, has a vital role in defining properties of alternative infrastructure within squatting spaces. These results underscore the symbiotic relationship: urban renewal affects and is affected by the squatter movement, and vice versa. Contributing to new urban dynamics in Copenhagen.

2.3. Conclusion

The quite complex story of urban dynamics in Copenhagen, through squatters and urban renewal, unfolds at least two or even more times over. Once considered as disruptors, squatters are strategic occupiers of space, hence this kind of adaptability and resilience. This recent role of squatters as participants in urban renewal points toward the very fine dynamics with municipal policymakers in shaping landscapes toward the future. Their transformative impact has tended to highlight the dynamic interplay between grassroots movements and municipal initiatives. Squatting thus became a counterforce not only in reaction, but also as a proactive element in the formation of alternative urban space and new definitions of the city-building process.

Indeed, this historical comparison in Table 1 reveals still more the dynamic relationship of urban renewal with the squatter movement. Indeed, the negative correlation of extensive urban renewal with the vitality of the squatter movement speaks highly of the intricate dance between these two forces. In any case, urban renewal designs the impact on public spaces and normativity and it is thematically very strong in the definition of the survival space and alternative infrastructure of squatter-occupied areas. This symbiosis is consistent with ongoing mutual interrelation in which urban renewal reacts and affects evolving dynamics of the squatter movement, eventually contributing to Copenhagen's distinctive urban landscape.

3.0. FOLKETS HUS, A THEATRE OF THE SYMBIOSIS OF THE SQUATTING MOVEMENT AND URBAN RENEWAL

3.1. Folketshus and Folkets Park

Folkets Hus emerged in 1971 when local residents and the slumstormer movement established Folkets Park on a disused lot in Nørrebro. After the municipality repeatedly dismissed requests for green space, activists proceeded to occupy a nearby vacant factory building—which they called Folkets Hus—to defend and complement the new park. The area was slated for demolition under municipal “bysanering,” prompting ongoing conflict between grassroots organizers and city officials.

Over time, persistent efforts—petitions, negotiations, and demonstrations—secured partial municipal recognition of Folkets Hus as a self-governing cultural venue. By the 1990s, the house had evolved into an officially acknowledged culture house, yet it retained its activist ethos by remaining user-managed and rooted in the original squatters’ aims.

From the start, Folkets Hus and Park sat at the intersection of local needs and city-level redevelopment agendas. Proposed construction projects regularly threatened both the building and the green space, leading residents to form negotiation groups (e.g., Folkets Park Initiativet) that blocked bulldozers and won support from trade unions and neighborhood associations. While city authorities at times recognized the park’s communal benefit or the house’s cultural importance, these acknowledgments often came only after extensive public pressure and political maneuvering. The ensuing decades thus embodied a push-pull dynamic: activists asserting a “right to the city,” municipal institutions seeking regulated redevelopment.

3.2. Architectural ethnography on Folketshus

The concept of 'Architectural Ethnography' originates in the unconventional discipline of 'Modernology,' established by Japanese architect Kon Wajiro in the 1920s. Wajiro's early work, such as the 1925 survey near Honjo Fukagawa Slums, laid the foundation for the intersection of architectural analysis and cultural observation. This research methodology has gained prominence globally, influenced by folklore and ethnographic principles within cultural studies. The 2018 Venice Biennale dedicated attention to 'Architectural Ethnography,' with architects like Momoyo Becjima and theorist Laurent Stalder showcasing two decades' worth of research results in this field. The methodology's roots in examining Western architecture through an anthropological lens, especially during the 1960s(Riggs 2015), signified a transformative period in architectural discourse. As a qualitative research approach immersing researchers in the studied community or organisation (Caulfield 2020), ethnography gains a unique dimension when applied to architecture. The reproduction of the scene allows the whole design process to give feedback to the unfiltered details. "As if" see "and" a "at the same time the general situation, based on a variety of elements, the material entity are in the form of links, Form in structure "((Kuroishi 2000)). Here, as a way of thinking, drawing makes description "characteristic of allowing self-evaluation and self-development (Tsukamoto 2003)".

This method is paramount in researching ethnography and aligns seamlessly with the ever-changing, multifunctional character of Folkets Hus. It allows for a visual and culturally sensitive lens with which one may fathom intricate dynamics. The importance of reflection and ongoing development in the research process underpins the ability of architectural ethnography to provide a self-critical medium. Here, I have carefully put together an architectural record of Folkets Hus combined with interviews, historical data, archives, and research on-site using the method of architectural ethnography. This way, there could be a detailed analysis of the building through the richer historical background of Folkets Hus within its evolvement process and cultural and social impact on the community.

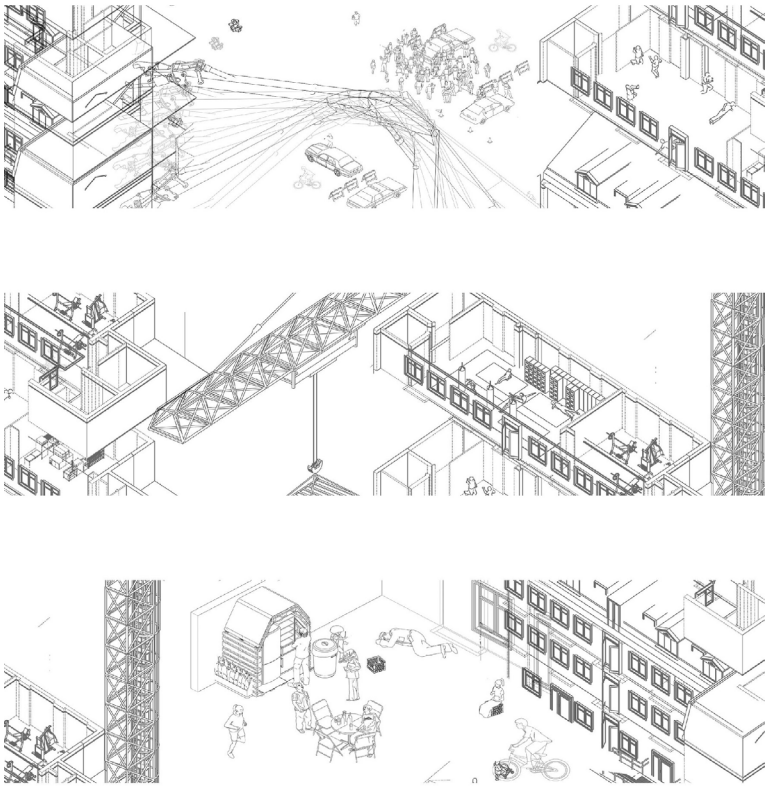


Figure 2: Architectural Ethnography on Folketshus. Source: (Author 2023)

An architectural ethnography approach to Folkets Hus helps uncover the layered symbiosis between squatting and urban renewal by documenting not only the physical transformations of the building but also the social, political, and cultural networks that interlace it. This methodology—drawing on participant observation, interviews, archival materials, and crucially, positional reflection by the researcher—clarifies multiple facets:

Through floor-plan sketches and historical photos, one sees how the factory layout was adapted over time to accommodate music rooms, communal kitchens, meeting halls, and eventually a café. Each change reflects the residents' evolving negotiation with municipal safety codes or funding stipulations.

Ethnographic observation of gatherings, maintenance days, and community kitchens reveals how the house operates as a collective: from decision-making assemblies (where users vote on changes) to day-to-day chores (carried out by rotating volunteers). These practices embody the notion that a once-squatted space can become a stable social institution without losing its grassroots ethos.

Interviews with long-term residents and municipal officials illustrate tensions around ownership, liability, and policing. Ethnography captures how the "official" city administration gradually came to accept Folkets Hus as a legitimate cultural venue—albeit with periodic conflicts that questioned the house's autonomy.

An ethnographic lens requires ongoing self-critique by the observer, recognizing that the researcher inevitably plays a role in shaping narratives. For instance, attending house meetings might grant certain trust or encourage more candid conversations, while simultaneously making local authorities cautious about sharing city-planning documents. Such reflexivity ensures that the final portrayal of Folkets Hus acknowledges both the open, participatory ideals of the squatters and the institutional frameworks that continue to circumscribe them.

Through these overlapping domains, architectural ethnography exposes a layered symbiosis: Folkets Hus exists in a simultaneously cooperative and contentious relationship with official urban renewal strategies. It thrives because municipal agencies ultimately allowed it to remain—but only after residents demonstrated its value as a communal cultural space. The house's user-driven governance aligns with Lefebvre's notion of the "right to the city," emphasizing collective production of urban life. Yet the official acceptance also imposes boundaries, such as fulfilling safety standards or contending with short-lived attempts to privatize or redevelop adjacent parcels of land.

3.3. Conclusion

Over the last 50 years, Folkets Hus has become a hub of local political, cultural, and social activities, thus showing its versatile nature in holding a variety of activities. This rehabilitation process, as conducted through joint meetings with the group and administration called A-gruppen, managed to achieve a high degree of collaborative nature through its intricate relationship with the Squatter Movement and Urban Renewal. This is what makes Folkets Hus an academic canvas on which the narratives of grassroots resilience, cultural richness, and community engagement are written out in the different dynamics of Copenhagen's urban landscape.

Architectural ethnography of Folkets Hus gives a thorough view of its multi-complex dynamics through a visually and culturally sensitive lens. On the other hand, looking at its history, evolution, and cultural-social impact, it presents Folkets Hus as a dramatic phase in the interaction between Urban Renewal and the Squatter Movement.

4.0. NAVIGATING THE INTERSECTION OF SQUATTING MOVEMENTS, URBAN RENEWAL, AND THE RIGHT TO THE CITY IN COPENHAGEN'S EVOLVING LANDSCAPE

The squatting movement in Copenhagen is developed in a very diverse landscape of struggles, but strong gentrification pressure, legal limitation, and very lively socioeconomic change are of prime importance. Gentrification—illustrated by rocketing property values and increased commercial development—threatens the affordability and availability of important squatting spaces. At the same time, the place is hampered to develop long-term communal and cultural squatted areas due to strict legal frameworks, including eviction procedures and anti-squatting laws, which increases the struggle regarding the right to the city. At the same time, this is further complicated through adaption to the changing global socio-economic landscape that demands flexibility to bring address towards the community demand relevant to economic factors, employment opportunities, and affordability in terms of housing. It is within this difficult context that the history of the squatting movement carries opportunities for resiliency and innovation, with their efforts being at the forefront, working proactively along with any urban renewal.

The possibilities of the squatting movement are strategic to move toward a collaborative and adaptive future. More community involvement, in the form of collective efforts and alliances, further strengthens the movement inside out and demands broader support from the rest of the community, fostering a collectivist approach to urban development. In this manner, the movement legitimizes itself and garners support by aligning with community interests regarding housing in a general sense of the term. The strong emphasis on culture and art in squatter spaces enhances alliances that, in turn, place squats as valuable assets towards the city's cultural development. Adaptive collaboration with urban renewal initiatives through constructive dialogue with municipal authorities allows the movement to contribute further to inclusive urban renewal strategies, recognizing the potential coexistence of squats within broader redevelopment strategies. Such an approach, by definition comprehensive in nature, would imply that the movement is dedicated to modern urban problems and the shaping of a more inclusive, more resilient, and more democratic urban realm.

This, in the future, requires strategic actions at the nexus of squatting, renewal, and the right to the city. Advocacy is also needed around the policy shift to ensure that squats' socioeconomic contributions are taken into account alongside reforms in restrictive laws and frameworks that undergird communal living. It would incorporate participatory voices of squatters into urban planning procedures, ensuring the squatters have a say in contributing to urban development that truly satisfies various community needs. The third dimension in which the squat is legitimized as a cultural heritage site therefore follows in this same right-to-the-city spirit: it acknowledges the different ways in which residents contribute to urban life. Platforms for inclusive dialogues, advocating for urban policies that are flexible, investment in capacity building, fostered international collaboration as well show the way for the future in which the squatting movement shapes an active Copenhagen with an inclusive, resilient, and democratic urban environment.

CONCLUSION

The squatter movement in its complex relation to urban renovation in Copenhagen is the subject of this paper. Utilizing architectural ethnography and historical research, the paper speaks to the understanding of Henri Lefebvre's notion of the right to the city and highlights the changing dynamics that are currently taking place within the architectural fabric of the city. This article builds on Lefebvre and David Harvey in understanding squatting as a materialist spatial practice of the right to the city. The squatting movement in Copenhagen that has been portrayed through a dynamic chronology shows adaptability and resilience when social and political landscapes changed. The movement is strategic in engaging with different neighborhoods, contesting authority, and contributing to a dynamic and inclusive urban spatial distribution.

In such a context, the interplay between the squatter movement and urban renewal dynamics uncovers an intricate and diversified storyline of resistance and collaboration. Though they look like disrupters at their beginning, squatters represent one more political player that will have to work in favor of the processes of urban regeneration. The complex relation between the two forces is emphasized through historical comparison in Table 1. The influences of urban renewal on the vitality and survival space of the squatter movement are emphasized.

Folkets Hus embodies, in the perspective of architectural ethnography, a theater of symbiosis between the squatter movement and urban renewal. The transformation of the former factory into a self-governing cultural centre realized the collaborative essence of grassroots activism and municipal development. The approach of architectural ethnography gives the reader a broad scope over the historical process that underpins the life of Folkets Hus, thus enhancing his or her understanding of complex dynamics.

This paper presents challenges at the intersection between squatting movements, urban renewal, and a right to the city. The challenges are driven by the pressures of gentrification and legal restrictions fueled by socio-economic shifts. Opportunities for the squatting movement lie within its rich urban history—to innovate and engage with urban renewal efforts, not as beneficiaries but as co-creators, through strategic community engagement, advocacy for affordable housing, and adaptively collaborating with urban renewal initiatives. This paper ties the need for strategic

actions toward policy advocacy, participation in urban planning, recognition of squats as cultural heritage sites, and international collaboration in forming a more inclusive, resilient, and democratic urban environment in Copenhagen.

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Critical Inquiry

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ABSTRACT: A new required course linking architectural and critical theories in the Bachelor of Architecture curriculum of the School of Architecture at the University of Arizona was developed in order to provide a hinge between the predicated courses of the core curriculum and students' choice of a Research and Innovation (R&I) track for their final three semesters of study, culminating in a Capstone Project. Featuring a plurality of voices in the instructional team, the course, Critical Inquiry (CI), broaches theoretical lenses for equity, ecology, and architectural agency, framed by an introduction to critical theories and research and a conclusion that showcases contemporary critical practices. Students are required to formulate a research project proposal meant to help chart a curricular path that will inform their R&I choice a semester later. This paper discusses our pedagogical innovation, our research into the course's realization of individual and institutional objectives via assessment activities with multiple stakeholders, and the iterative refinement of the course that has resulted. That refinement has affected the content and sequence of course topics, and the overall scope of the class, from its inauguration in 2020 through the pandemic, the rise of the Black Lives Matter movement, and other socio-cultural and political developments. CI increasingly approaches our goals to address equity, diversity, and inclusion in our professional curriculum and prepare students to construct and assert their individual agency during the final stage of their education.

KEYWORDS: architectural pedagogy, theory, research, equity, agency

INTRODUCTION

This co-authored paper presents our shared and distinct reflections on a critical theories course which we co-teach in the School of Architecture at the University of Arizona. As a required course in the professional Bachelor of Architecture program, and the fourth in the school's History and Theory sequence, Critical Inquiry (CI) seeks to expose students to contemporary theories that advance equity and justice and empower students by framing distinct kinds of research that can inform architectural practice. While a worthwhile and successful endeavor from the beginning, the course has presented the opportunity for a pedagogical journey—for us two co-instructors, together with colleagues and students. After a first offering in the spring of 2020, we radically re-tuned the structure, content, and goals of the course to better grapple with the myriad inequities that manifest in built environments and through spatial practices. We navigated the onset of the pandemic, a temporary pivot to online instruction, student and faculty fragility, the summer of George Floyd, and student protests. These things changed us and changed the course. This is a reflection documenting our pedagogical project of the last five years.

We discuss in turn the rationale for and origins of the course, its strategic position within the curriculum, its collaborative logic, thematic structure, evolution in response to critical issues and sudden events in the world, and our own proactive, iterative assessment and response through further refinement. The paper concludes by reflecting on the impact of research within the course and our research about the course with ongoing potential for the pedagogical project between us and with our students.

1.0 COURSE DESIGN AND REALIZATION

1.1. Curricular origins

The idea for the course began as a response to observations by studio faculty colleagues that our students were not sufficiently versed in architectural theory nor in contemporary architecture. As a scholar and teacher of the history of art and architecture, Laura Hollengreen agreed. The edge condition of having been trained in another discipline (History of Art) and working on pre-modern as well as modern topics while teaching for many years in schools of architecture, including thesis prep in collaboration with studio colleagues, offered the perfect vantage point of expertise and critical distance from which to conceptualize the new offering.

Rather than distributing responsibility across studio courses for theoretically informed introductions to contemporary architecture, Hollengreen proposed a stand-alone course titled "Forms of Critical Inquiry and Expression" that would systematically cover a spectrum of topics. She devised the skeleton of the course, both in topics and assignments, based on the model of an earlier Capstone Preparation course she had taught to fifth-year students in which they conceived their year-long, independent Capstone Projects. Already at this point, the new CI course was intended to empower students and initiate their transition from a sequence of highly coordinated, professor-driven required courses to self-driven identification and definition of their interests leading to compelling Capstone work.

1.2. Curricular positioning

Critical Inquiry (CI) was designed to bridge the predicated core curriculum and the thematic choices students make when entering our program's final three Research and Innovation (R&I) semesters. Taught to third-year students just past the mid-point of the five-year curriculum, CI aims to serve as a hinge in the curriculum, introducing students

already endowed with skills to multiple theoretical lenses, to research in architecture, and to diverse drivers for innovative practice as they prepare for their final semesters of study. It is also strategically timed to conclude the four-semester history and theory sequence, which now arcs from chronologically and geographically organized topics (History I&II) to more theoretically informed themes examined in relation to 20th-century architecture and urbanism (History III), to a course entirely dedicated to theoretical lenses revealing systemic structures that inflect constructed environments and their impacts on lives and lifeways.

Foregrounding diverse contemporary critical issues and practices, the questions we ask in CI shift away from investigating and interpreting the past to speculating about the present and future. The weekly topics expose students to relations between entrenched systems and their manifestations in built environments and also familiarize them with exemplary critical and creative practices, projects, and propositions that address the grand challenges of our times.

1.3. Collaborative ideation and teaching

While scaffolded by one individual and initially projected to be solo-taught, the potential to co-develop and co-teach the new course presented a unique opportunity to articulate diverse theories, positionalities, and methods dialogically.

As Hollengreen was preparing the first offering, Beth Weinstein joined as co-instructor. As a faculty member primarily responsible for studio teaching and courses in the building technology sequence (drawing upon 20 years of practice before joining the faculty), Weinstein had also previously taught histories, theories, and techniques of representation. In 2020, she had just returned from earning a mid-career, practice-based Ph.D. in Creative Arts (Installation and Performance) and was seeking new responsibilities in the curriculum that would be more aligned with her interest in critical theories and commitment to social, political, and ecological matters of concern. Joining Hollengreen presented a perfect opportunity, at once collaborative and co-creative.

When Weinstein entered the scene as co-instructor, CI became much richer before even its first offering in Spring 2020. The sequence of topics remained similar to what had originally been laid out, yet now the course provided two different voices in lecture, in alternating weeks. A year later (2021), it became even richer when a third colleague, who otherwise taught digital and fabrication technologies, joined the team to lead several of the associated discussion sections. We collaborate—most recently with *four* other colleagues, of whom one is from outside the discipline of architecture—in offering discussion sections that are a novel experience for most students in our large professional program. Indeed, the discussion sections are open, informal spaces where students can grapple with the complex ideas of the course, hone their theoretical chops, and practice debating ideas and articulating their own perspectives.

Consistently, we coordinate instruction within our agreed-upon thematic structure and frameworks for assignments but speak from our own perspectives, positionalities, and different bodies of expertise in a rich and generous atmosphere of mutual respect. We model an extended dialogue, engaging, questioning, and often surprising one another. As a co-taught course, CI structurally challenges mono-vocal and singular perspectives normative to the sole-lecturer format.

2.0 THEMES AND STRUCTURE

2.1. Disruptive world events and thematic change

Some of the above scaffolding and team building is relatively straightforward for instructors of record delivering a new course, but there was nothing straightforward about what happened in spring 2020. After reading news stories about strange illnesses in places far from Tucson, we left for spring break and never came back. Our course, like every other, instantly pivoted to a synchronous online format. We supported one another and the students as best we could. The summer brought some relief from teaching and campus matters until the murder of George Floyd by a Minneapolis policeman. In the wake of that, US campuses came alive with students, alumni, faculty, and staff demanding a reckoning with the unjust treatment of Black members of our communities. At the University of Arizona, a new campus advocacy group called COBA (the Coalition of Black Students and Allies), wrote a letter to the dean of the College of Architecture, Planning and Landscape Architecture urgently arguing for changes. Faculty and administrators held listening sessions with stakeholders and we planned a “re-entry” to campus that in the end was quite partial; still, during this year of upset, the first year of the pandemic, everyone quickened to the task of imagining how better to support vulnerable and disenfranchised people among us. In particular, we felt the urgency of reckoning with systemic injustice and with our own educational and racial privilege teaching an increasingly diverse student body.

Events in the world made it evident that the course, as originally conceived, hewed too closely to perspectives already well broached elsewhere in the curriculum—e.g., Critical Regionalism, phenomenology, and sustainability, topics which have defined the identity of our school for some time but were ripe for (re)contextualization in terms of other issues. We had designated one of our course’s original topics “Identity, Culture, and Community,” but even pluralizing the topic headings failed to give adequate recognition and consideration to the multiple identities, cultures, and communities excluded from and by built environments, nor to the far from inclusive, far from just treatment of Blacks and other minorities in our midst. A week dedicated to “Systems Thinking and Sustainability” which we had also enunciated as an initial topic similarly needed expansion to address systemic racism, sexism, and ableism, denigration of the poor, environmental degradation, rampant consumerism, and the impacts of all these forms of “slow violence” (Nixon 2011) on humans, more than humans, land, and settlements.

Thus, topics bifurcated, expanded, and shifted to give greater gravity where overdue (Figure 1).

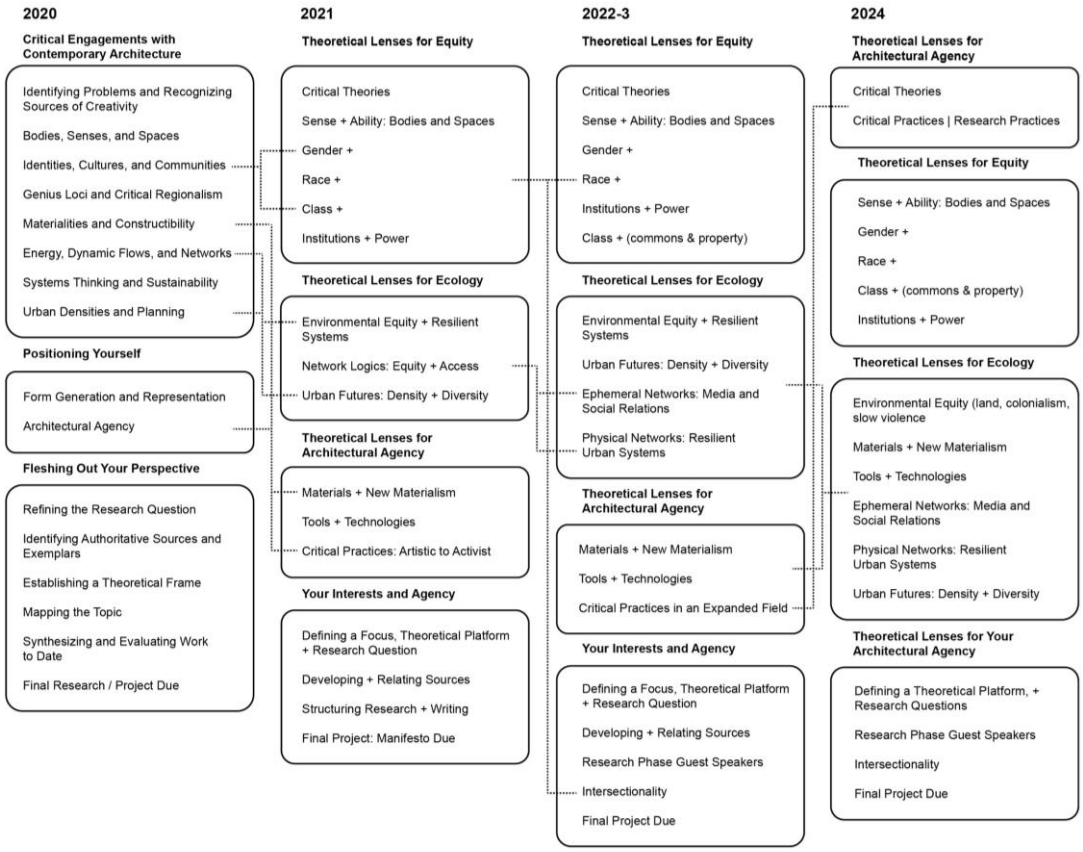


Figure 1: Curricular content transformation (2020-2024) as we learned from the world and one another. Source: (Weinstein 2024)

We quickly moved away from traditionally dominant topics such as “Genius Loci and Critical Regionalism,” a theme that has tended to occlude other frames of reference in our school, and towards such topics as gender, race, class, and institutions and power that broached the spatialization of discrimination, the ways it “takes place” (Lipsitz 2011), empowering some at the expense of others. Students learned about entanglements of space with neurodiversity and women’s labor, about emergent queer spaces, redlining and pernicious designations of urban blight, density and poverty, and much more. Our students—be they educated in Catholic schools in the Sonoran Desert borderlands or in Islamic schools in the Middle East, those expected to turn their cameras on during class Zoom meetings when they were back in their parents’ homes or those chafing at post-violence security measures on campus—all let us know what disciplinary environments felt like on a daily basis. Indeed, a sharper focus on the criticality of theory electrified many students in our increasingly diverse student body. Most of them had not previously had their legacy—as first-generation college students, people of color, first- or second-generation immigrants, or international students—count as part of the discourse in their architectural classrooms.

We also sharpened our attention to externalities of an environmental nature, their unequal impacts on indigenous and other local populations, and, at times, the aestheticization of the “toxic sublime” (Peeples 2011) in various media. We broadened discourse around materials through the lens of new materialisms and posthumanist thought and questioned our engagement with tools and technologies as extensions and sometimes displacements or usurpations of human presence, ability, and judgment. We presented urban systems in the context of dramatic increases in density and disastrous climate effects. We also sought to highlight horizons of thought, debate, and action in the world of exemplary contemporary practitioners with their different models of critical practice.

2.2. Thematic structure

Under three umbrella topics—Theoretical Lenses for Equity, Theoretical Lenses for Ecology, and Theoretical Lenses for Architectural Agency—that were introduced in the second offering of CI in 2021, we began to weave through threads even as we shifted roles and lenses each week of the semester. “Theoretical Lenses for Equity” focuses students’ attention on how our society is constructed. The following course theme, “Theoretical Lenses for Ecology,” helps them examine the impacts of their chosen profession. This unsettles what students assume to be stable ground, shaking and re-laying conceptual foundations and multiplying the positions and perspectives from which design is generated. Throughout the course but most pointedly in “Theoretical Lenses for Architectural Agency,” we encourage students to question what architects and researchers do and why, how, and for whom they work to transform built environs through architectural acts. From neurodiversity (Manning and Massumi 2014) through perspectives of race (Cheng, Davis & Wilson 2020; Lipsitz 2011), gender (Brown 2011; Butler 1988; Urbach 1996), and class (Deamer 2015; Wright 2009) to relationships between design and institutions and power (Foucault 1995), physical and ephemeral networks (Augé 2008; Virilio 1998), and urban density and diversity (Baker 2012;

Davis 2006), we proceed to environmental resilience (Bennett 2010; Ingold 2011; Kaika 2017) and models of critical practice (Schneider & Till 2009). In all three of our course parts, we stress intersectionality, justice, and performance—performance of identity, spatial performance, and intellectual and creative performance in architecture and research.

Each of us has a shelf-full of the standard anthologies of contemporary architectural theory (Nesbitt 1996; Jencks and Kropf 1997, 2006; Leach 1997; Hays 1998) and we do still draw a few texts from these helpful volumes. But with an assemblage approach, we also select more heterogenous sources drawn from other disciplines, current architectural essays (*Log; The Funambulist*), and non-textual media. This is a guided tour through less frequently trodden lands: we don't disguise our own passions and scholarly commitments; instead, we model what it is to draw a matter into personal and professional question, to frame distinct topics and practices with theories, to build appropriate research methods, and to develop authoritative perspectives.

3.0 RESEARCH POTENTIALS

3.1. Teaching research design

We contribute to the provision of opportunities for undergraduate students to pursue their own research, even as we celebrate occasions to link our own research and teaching. As two faculty at a Research I institution, with doctorates in disciplines other than architecture and teaching professional architecture students, we present research *for*, *about*, and *through* design (Downton 1996) as part of what can occupy the "space between" the paradigms that K. Michael Hays outlined as the place of critical architecture (1984). In addition to our shelves of architectural theory, we each have gathered manuals on research methods in architecture (Groat and Wang 2013; Lucas 2016). Nevertheless, we realize that research manuals are too formulaic and narrow and even many up-to-the-minute journal publications are too technical and detailed to serve as models for our students. As those students are still developing core skills of design, our goal is to make research a part of the sequence of activities that informs their design process. Just as architects manage the flow of information from many sources into design, we wish to model how one charts a course between knowledge of what other esteemed, inventive thinkers and designers do, on the one hand, and matters of personal concern, on the other, in order to develop a perspective and viable approach that is one's own. In a similar exercise, choreographed through their reading and writing in the course, students gain confidence in articulating their interests and ideas.

This is where end-of-semester research project proposals come into play. Along the way, investigations by students in the class take multiple forms. Initially, they prepare to lead and participate in discussion sessions, define terms through short keywords assignments, and craft somewhat longer but focused essays. Later, at the end of the course, they formulate a research project proposal scaffolded piece by piece through topic identification, construction of a bibliography, framing of research questions, discussion of key terms, analysis of exemplary authors and works, and mapping of their own further learning via additional proposed coursework. The course thus culminates by asking students to propose an architectural research project—not to carry out the project, but to understand what one needs to do to formulate a credible proposal for individual research. At a time when many students do less and less long-form writing, we ask for a well-developed and well-argued prospectus that rehearses the process by which research-practitioners define and make a case for their investigations. In this way, students begin to light the way into their own unknown futures. It is critical to us that we build in students *courage* to conceive of fresh ideas, *confidence* that the expression of those ideas can grow in rigor, precision, and thoroughness with writing and speaking practice over time, and *curiosity* about the many genres of expression worth exploring.

3.2. Curricular bridge to research-informed design

At the same time that we debuted CI, our school's B.Arch curriculum adopted a new structure for the final three semesters of students' study. Students now choose among multiple Research and Innovation (R&I) tracks which are thematically coherent sets of studios and electives leading to the culminating Capstone Project. CI has thus served as a moment of articulation for students, preparing them to make an informed choice of track that corresponds to their emergent interests. We lift the lid on a Pandora's box of questions just as students come to the end of the core curriculum comprising coordinated studios, history courses, professional practice classes, and digital, structural, material, and environmental technology labs. Indeed, CI is timed in such a way as to contextualize this earlier topic coverage within broader architectural discourse and in relation to world issues.

The R&I phase presents students with faculty-initiated and co-authored themes that assemble existing and prompt new courses under titles such as "(Meta)Physics of Light," "Tectonic Inquiry," and "Urban Agency." Each R&I track offers a selection of advanced studios and electives (practical, technical, and theoretical) as well as a specific methodology for developing a year-long Capstone project, with related sites and scales for investigation. The beauty of these tracks is that, like our CI course, they invite faculty as well as students into new conversations and collaborations and they demonstrate a good breadth of issues in and approaches to architecture. Once students can identify their interests, they can choose electives in a concerted way for more coherent, deeper knowledge construction in a thematic area and can then apply what is learned in those electives to a Capstone studio.

Crucially, CI seeks to empower students to take an ethical position and assert their own agency regarding the culmination of their undergraduate design education. To prepare students for the R&I phase, CI explicitly asks them, perhaps for the first time in their architectural education, to reflect on the following questions: "How and why do I design? For whom, through what means, guided by what research questions, methods, values? Where, in fact, do I stand?" Through CI, students rehearse a more agentic and (self-)critical attitude towards an expanded architectural field of practice and research; they formulate research questions, propose methods of inquiry and applications, and

chart a prospective curricular path to pursue. In a “safe,” hypothetical scenario, they speculate about how they will engage in research for, about, and through design, testing the waters. This rehearsal of a research process prepares them to articulate their R&I path during the subsequent semester, so that they are intentional about a group of students and faculty with whom they choose to affiliate and the assemblage of seminars and studios that support their agenda. Throughout, we coach students on how to produce work that is rich enough to capture the imagination and precise enough to be credible.

3.3. Research to inform research-design pedagogy

Over the four years of CI’s offering, we have solicited feedback from co-instructors, other faculty colleagues, and our students. Not only have we been proactive about reviewing student feedback through formal university student course surveys, but we have also initiated informal surveys during the Covid-19 pandemic and post-course surveys of students currently enrolled in the R&I tracks or who have graduated. In addition, through school fora, Capstone committees, and faculty surveys, we have solicited feedback from peers (particularly those coordinating R&I groups and those teaching Capstone) regarding ways to improve the link from core to R&I and Capstone. In addition, our co-teaching team has benefited from live feedback from team members who coordinate and/or teach various courses within R&I groups. This feedback has shed light on gaps in students’ awareness of potential trajectories, actual course offerings, and Capstone options, as well as on students’ understanding of research as it might condition design and their power of self-determination.

In addition to our own self-reflexive observations and critical assessment, the feedback described above and sampled below has been vital to the process of learning about, for, and through teaching of research-design, creating conditions for student empowerment and a culture invested in equity and inclusion via the form and content of our pedagogy.

4.0 STUDENT, ALUMNI, AND FACULTY RESPONSES

4.1. Student demographics

In the years that we have been teaching the course, our student population has changed significantly: students of color now comprise more than 55% of our college’s undergraduate total; women are more than 53%. The University of Arizona has been accorded the federal designation of Hispanic Serving Institution (HIS) and the number of international students has increased. In addition to differences of gender, race, and class, some of our students are veterans, some have physical or cognitive challenges, and some struggle with their mental health. They teach us as much as we teach them.

4.2. Student course survey (SCS) comments

Some students have found the course overwhelming:

> The class does make some interesting points, but the lectures often made it feel like it’s all on us to fix the problems of the world, which sometimes feels very daunting (ARC435 SCS 2023).

Others enjoyed it, deeming it distant from the discourse in their other classes:

> I enjoy the deep dive into these topics which a majority of people are afraid to touch and examine on this sort of level. It was a great challenge and eye opening to see all the ways architecture can influence and change our world (ARC435 SCS 2022).
>
> I enjoyed the way these topics were brought and discussed in the course. With respect, but attention on topics no one had ever really spoken to us about (ARC435 SCS 2023).
>
> I thoroughly enjoyed the discussions in this class and an emphasis on topics that are widely disregarded, such as race, gender, and institutional power (ARC435 SCS 2023).
>
> I enjoyed being able to tackle topics that were previously locked from my view of architecture and how it interacted and produced effects on the world. I especially enjoyed being able to apply these to my design process this semester which I believe has improved most this term (ARC435 SCS 2022).
>
> [N]o busy work–inquiries into the pertinent aspects of existence beyond, and because of, architecture’s triviality (ARC435 SCS 2022).

Yet others thrilled to the open-ended discussion of frames of reference and the invitation to locate themselves among the issues highlighted by the theories we read together:

> This class was one of the most interesting ones I’ve taken. It really made me think critically about my own design practices and about outside factors that effect [sic] them (ARC435 SCS 2023).
>
> This class should be a required course, the topics discussed and examined are CRITICAL for the new generation of architects. The information and discussions are some that will guide me for the rest of my career (ARC435 SCS 2021).
>
> This [discussion section] motivated me to actually engage with the material presented in lecture, and made this class relevant to my architectural education. There was a lot of rigor, accompanied by scrupulous organization, which made the rigor stimulating and motivating rather than overwhelming; kudos for striking this rare balance (ARC435 SCS 2023).

4.3. Alumni feedback

Alumni who took the course between 2021 and 2023 reported the following:

> Yes, ARC [435] played a major role in developing my personal design ethos and broaden[ing] my perspective o[n] architecture’s relationship between body, space, culture, politics, and society.

> Yes, it put into perspective many concepts about marginalization and social practices that I had not previously considered, and helped me understand how they influence design and how design can reinforce marginalizing practices. It also … shifted how I experienced the built environment.
> This course introduced me to the totality of forces at play in defining our interaction with landscape or our architecture.
> Exposure to the depths and incredible specificity possible for an architectural inquiry is the highlight of the course in my mind.

Most respondents professed admiration for the range of course coverage and their exposure to critical theories, though some noted that the connection to practice remained elusive to them and only half deemed the course to have been significant in informing their choice of R&I track.

4.4. Faculty feedback

One seasoned Capstone instructor learned from his cohort of students that CI "helped frame how to ask questions." Another more recent Capstone instructor whose research-practice is more scientific found that students had developed a sense of the expanded field of architectural practice, including "social and cultural issues, and health and wellbeing." They additionally had a "good foundation and awareness of theoretical perspectives." However, our colleague's opinion was that, in spite of awareness of areas of inquiry and issues of concern, students had still not fully developed skills of "formulating critical questions, or rather good research questions for their [group Capstone] projects."

5.0 ARCHITECTURAL AGENCY

Informed by four years of data gathering and reflection, our latest iteration sought to invigorate and foreground the theme of architectural agency, lest the broad theoretical reach of the class overwhelm students' sense of the tools and skills at their disposal to make spaces that are accessible, healthy, sociable, and just.

5.1. Space for criticality: theirs and ours

We begin the class with the K. Michael Hays *Perspecta* text on critical architecture (1984), a text that, like others we assign by Paul Virilio (1984), Michel Foucault (1979), and Dolores Hayden (1975), is not recent. While it and those others remain powerful enough to assign and have a long legacy, the world has moved on and paradigms for architecture are no longer confined to the binary Hays presents: architecture as tethered to dominant culture or as autonomous creative endeavor. Indeed, there is such a philosophical, theoretical, and ethical ferment of ideas now that we are able to emphasize to students the *variety* of possible points of departure, frames, and drivers for their design work with the myriad intersections, in-betweens, emergent complexities and entanglements as conceptual terrain inviting, indeed demanding, investigation.

The course succeeds in helping many students gain in confidence in their research skills, thinking, and writing:

> This class helped me adapt ideas I was already considering into full-fledged thoughts. I developed a strong passion for research that I did not previously realize I was capable of (ARC435 SCS 2023).
> Amazing class! Learned so much throughout the whole semester. The project and type of writing assignments we completed made me feel smart and educated (ARC435 SCS 2021).
> I finally learned just how powerful words are (ARC435 SCS 2023).

Taking to heart the course's meta-level objective of bridging from core to research and innovation, as well as fostering student empowerment and agency, we have repeatedly tuned the course. In response to our own observations of students' struggle to understand research, their questioning of its value and how to engage in it, and reinforced by faculty peer feedback, we have just this year brought topics of critical inquiry, critical practice, and research-practice to the first weeks of the course, making explicit that the weekly lecture content exemplifies research in relation to practice. In this latest and most successful iteration, we split "Theoretical Lenses for Architectural Agency" into two segments, with the latter being "for *Your* Architectural Agency." This pairs a front bookend—on critical practice and research in relation to architecture generally—with a concluding bookend on students' own architectural research trajectory.

Discussions, writing exercises, and project proposals aim to rehearse, develop, and articulate students' interests in critical issues and grand challenges to be explored through research-practice. In addition, in response to our own observations plus faculty and student feedback that students enrolled in the core and CI are insufficiently informed about and aware of opportunities and choices in the R&I curriculum, we now dedicate course sessions to colleagues' presentations of R&I groups' primary research questions, methods, course offerings, and Capstone project framing. Research is not merely happening "out there," but also "in here" in the advanced studios and Capstone sequence.

5.2. Listening and learning

Listening closely to students, alumni, and peers, we have learned that students walk away from CI changed, unable to unsee what they have seen; this impacts their academic and professional trajectories. The most recent cohort of graduates praised the course as instrumental to their intellectual and ethical development as nascent practitioners and it empowered several of them to craft powerful independent R&I tracks. We have further iterations of the course ahead of us to assist students in developing an appreciation of the myriad ways they can and should research for, about, and through design, even if academia and research, in their purest forms, are not part of their projected

career paths. In addition, as we aspire to cultivate both technical and conceptual research skills across our diverse student body, we can only conclude that we, too, have to return to the drawing board again and again in order to refine our methods for introducing, modelling, and engaging in the activity of research.

5.3. Coda

In academia and architecture, authorship still matters, but it can be respected within a dialogic, relational environment—what Michael Benedikt calls “architecture in the second person” (Benedikt 2020). In this paper, we have raised our two voices together and separately. Each of us is associated with a different R&I track and different methodologies for studying the interface between architecture and the larger world. In a context of trust, we can experiment, we can try on new perspectives, and we can show ongoing evolution. Thus, we model how architects (and others) chart a course between not knowing, unknowing what is assumed, building knowledge of what diverse esteemed, inventive thinkers and designers do, examining (individual and societal) matters of concern, and embracing the unknown futures within and with which architects’ practices will unfold. The ultimate aim is for students to develop perspectives that are authentically and ethically their own.

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Beyond Arrival: Ethics in Housing Those Who Will Come

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ABSTRACT: The paper discusses ethics in architecture amid the design of asylum spaces in Europe. It queries the role of the designer in the building typologies of shelter and housing across the limitations that the contemporary asylum practice poses on the discipline, pointing out regulative, political, as well as historic and current societal aspects that critically inform the design sphere around asylum and the understanding of refuge – discussing global phenomena as much as local initiatives. In doing so, it not only works out features related to design types and methodologies, but it also reflects on the ambit in which designs are put forward, including official solutions, privately based collaborations, and university research or lab projects. Against the background of the most recent trends around standardization and design policies, the paper debates if there is an architectural leeway and its potential worth along theoretic and actual design contributions towards a humane contemporary architecture for refugees and displaced people in Europe.

KEYWORDS: design ethics, asylum architecture, invisible design actants, law and leeway in architecture

INTRODUCTION

If we assume that there is *ethics* in architecture, we thereby acknowledge its absence, or rather the existence of an architectural *non-ethics*. Sensing this absence is a way of critically reflecting on potential values of (an) architectural design and on the role of the designer who attributes them to it – based on morality. How, then, give meaning to the designer's individual knowledge of and practice along moral codes and define those as ethically, as socially responsible (opposed to being simple a response to problems)? Attorneys vow to constitutions, physicians take the Hippocratic Oath – how would an architect's oath come about? Are design actions, compared to other disciplines, merely a secondary set of value add to humanity? What are the aspects that limit ethical decision making in design?

1.0 NON-ETHICS AND INVISIBLE ACTANTS IN THE ARCHITECTIRE ARRIVAL

Arguably, architectural design includes a set of seemingly invisible aspects that strongly influence space making and its form: our modern societal expectations and our human patterns of behaviour are formed by our institutions that sturdily regulate our human relations through legal frameworks. Designers, then, adapt to the institutional regulations and assume the circumstances around the objects to be designed, concerned with giving the best possible form to predefined situations (Burckhardt 1980). In the vast field of architectural typologies particularly affected by regulatory bodies, arrival architectures, those structures built to welcome and accommodate asylum seekers, are situated right at the intersection between ethical considerations (as in societal acts of care and humanitarian aid) and aspects of legislation and political power. As such, they are part of an increasingly acute conjunction of architectural design and law, in which human rights and the sense of wellbeing (when it comes to spaces of habitat) seem to make way for political agendas – across the means of building codes, backing them up with the use of strong vocabulary that indicates a potential danger to the societal systems, such as *crisis, challenge, problem*, or *safety* (Misselwitz 2010).

When it comes to the practice of asylum, referring to both a political status and a physical place of refuge, the consideration of a designer's leeway towards ethical decision making seems particularly critical. On the one hand side, housing – principally for vulnerable groups such as refugees – requires the careful consideration of all those invisible design actants that influence the well-being of its inhabitants, such as dignity, safety, health, and inclusion (UN Habitat 2020). The establishment of standards, in this regard, is often considered an achievement towards the betterment of living conditions for a growing number of displaced persons and refugees (SPHERE 2018) – a number that has surpassed a saddening milestone of 100 million people for the first time in 2022 (UNHCR 2024). As of today, particularly in Europe, the arrival of asylum seekers is subject to a highly protocolized procedure with different phases and the spatial conditions surrounding those phases fall into the standardizations that, as in action fields of humanitarian aid around the world, rather reflect the applied logic of military or medical care than humanitarian aid. The contemporary humanitarian spaces in Europe mirror this logic and can be considered an indicator for the vicinity of humanitarian aid and our established systems of power and political will (Weizman 2014). If we consider humanitarian spaces as an interpretation of design policies that influence specific architectural decisions, the architecture of asylum seems to remain an inclined typology that signals various stages of welcoming and care that are subject to place, time, the institution responsible, and – (only) to some degree design aspects, as architect Brandlhuber underlines though his statement "Architecture begins with laws, not according to them." (Brandlhuber, Kerez, and Trüben 2016, 11).

Some of the resulting contemporary design features around the architecture of arrival in Europe can be pointed out here: they are considered temporary, often find themselves in secluded surroundings and non-urban settings, are protected (marked by fences or similar barriers), they are formed under extreme conditions according to sudden demands, and they show a certain uniformity in their spatial programmes. Along with the re-occurring use of structures that were never purposed to meet housing demands such as tents, containers, or former industrial and military sites, this contributes to a 'campization' trend across Europe (Kreichauf 2018). Broadly speaking, the design types around arrival architectures can be distinguished into swiftly erectable modular housing units, adaptations or transformations of vacant buildings, ad-hoc solutions using on-site materials, or entirely new constructions. The different design types can be detected in all the different groups of the existent accommodation, independent of them being first reception points, second line accommodations, or refugee housing (ibid). Much of Europe's humanitarian architecture seems not to put into place what it (or should) advocate(s) for.

2.0 CAUSES AND INFLUENCES AFFECTING THE CURRENT EUROPEAN ASYLUM PRATICE AND ITS SPATIAL COMPONENTS

The notion of asylum evolves dynamically, undergoing cultural, political, and economic transformations that parallel the swings in collective and individual societal practices of our time. Notably, for instance, the shift from sacral to statal asylum has altered its spatial condition and political significance. Formerly rooted in a combined act of physical and institutional care, asylum now leans towards a state of reception, a limbo where asylum seekers await the outcome of protracted procedures inside dedicated spaces. The physical aspect of asylum, once a refuge, has shifted into a realm of uncertainty, temporary solutions often transitioning from an intentional short-term condition to a lasting one with people living habitats that were never fit for housing purposes for ten years and longer (Albadra et al. 2008). Today's asylum practice is a relatively recent development, originating in 19th-century Europe and evolving in significance and practice over subsequent centuries in response to historic events (Misselwitz 2010). As mentioned, the current connection between refugee housing and design reflects a narrative centred on safety, shaped by the complex history of migration Europe and, more recently, the European Union's asylum policies of the last decade.

2.1. Asylum architecture during World Wars and the inter war period in Europe

The massive migration waves during and after World Wars I and II in the first half of the 20th century prompted architectural designers, including renowned figures like Le Corbusier and Alvar Aalto, to tackle mass housing challenges. During a research stint at MIT in the 1940s, Aalto experimented with a 'growing house,' strategically designed to evolve from hosting multiple families in an emergency state to becoming single-family homes (Schildt 1991). His work highlights how adaptable geometries can bridge the gap between basic shelter and more enduring housing, addressing a weakness in humanitarian shelter architecture through thoughtful design. In contrast, Ernst May, as the chief designer for Silesian refugee accommodations in the interwar period in central Europe, focused on the concept of a growing house rather on a material and logistical level, overcoming building material scarcity and addressing the urgency of post-war housing shortages in Germany (Herscher 2017). May's foresighted construction practices, honed through his experiences in the conception of refugee accommodations with specific housing qualities, contributed to the high standards of the massive settlement development in Frankfurt, distinguishing it from other housing projects of the time (Henderson 2013). Independent of their individual interpretation of what makes decent living conditions, what defines the narrative of both May and Aalto is the consideration of the building task not merely as an emergency requirement but as a contribution to increasing the national housing stock (Figure 1).

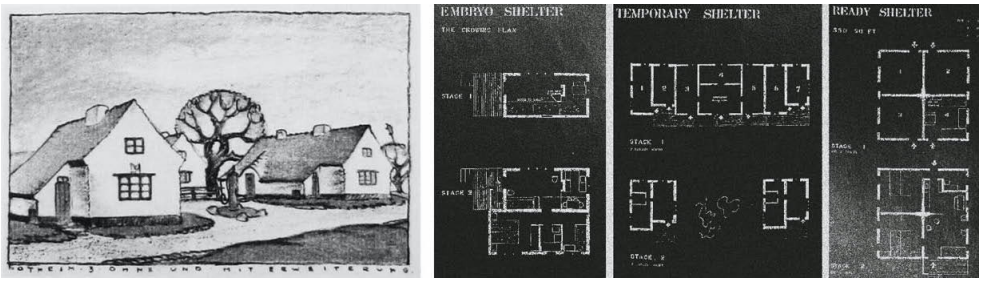


Figure 1: The designs of both Aalto and May showcase the concern with the general housing stock opposed to temporary solutions. Source: (Schildt, G., 1991. *Alvar Aalto – The Mature Years*. New York: Rizzoli Publishers, © Ernst May Gesellschaft, 2023.)

2.2. Post war Europe, the international community and its effect on humanitarian design

After World War II, nearly seven percent of the global population experienced displacement due to war-related events, destroyed habitats, or border redefinitions (Steigenga 1958). It's crucial to note that post-war migrants cannot be equated with today's asylum seekers and neither the reception facilities. Although various refugee accommodations were developed at that time to manage the massive influx of people relocating to new or former places of habitat, these were primarily military-oriented and served as transit and registration points. They made use of modular military camp structures and were not designed to address longer-term accommodation questions, as is, partly, the case today. This historical context may contribute to the diverse approaches designers take in shaping humanitarian spaces today, reflecting a departure from a unified design compass, a perspective also

acknowledged by architect Kristian Kerez: "Where there is an architectural consensus, there is no need for building laws" (Brandlhuber, Kerez, and Trüben 2016, 12).

The end World War II brought about the formation of the international community and shifted the discourse on housing refugees from the architectural realm to specialized institutions, such as UN agency for refugees UNHCR (Herscher 2017). Beyond monitoring the global numbers and movements of refugees and advocating for their rights, UNHCR assumes a crucial role in relief missions, shelter, and the accommodation of displaced individuals. The iconic blue-logoed tents and other structures serve as a visible link to these relief efforts. However, the involvement of UNHCR, coupled with the post-war establishment of firm territories and nationalities in Europe, has alienated refugees from the architectural housing discourse thus distancing them from designers' engagement. Rather than leaving refugee housing to informal channels, the response of the international community to migration has been formalized, assigning new roles to various actors authorized to engage in the humanitarian space, related to health, hygiene, infrastructure, and so on. The design of emergency sites follows an operational logic, making the creation of a humanitarian space a distinct bubble limiting designers' involvement to specific, defined parameters. Consequently, the typology of arrival architectures transforms into a heterotopian realm, existing outside societal norms and featuring stringent access restrictions (Foucault 1984).[1] While one might argue that architecture itself is neutral, the applied logic to asylum spaces underscores their heterotopian nature (Ebeling 2018).

Despite effecting design limitations, some architects actively pursue collaboration with UNHCR, exemplified by Shigeru Ban's and his critically reclaimed designs of the ‘Paper Log House‘, using polyurethane-coated paper tubes secured within sandbag-filled beer crates. These four-millimetre thick, ten-centimetre-wide paper tubes, available worldwide, offer protection from the elements, insulation, and ease of assembly in six to ten hours by unskilled workers. Ban emphasised that housing quality, whether for refugees or ‘on-order’, should maintain the same standards (Christian 2014). The aspects of time urgency, easy mobility, and swift assembly, naturally, dominate the task of designing basic shelter relief. Parameters that have informed the development of the ‘Relief Housing Unit (RHU)‘, emerging from the Better Shelter initiative in collaboration with the IKEA Foundation and a group of Swedish industrial designers. RHU units are modular, consist of a steel frame and semi-rigid floor and wall panels, are easy to assemble (within six hours), and meet internationally established living standards and can be transported flat-packed (Better Shelter Organization 2024). Although UNHCR in general promotes the use local materials for shelter (UNHCR 2024), RHUs have served over 80,000 people worldwide and only more recently seek for ways to integrate local resources (Better Shelter Organization 2024)(Figure 2).

Both design concepts concentrate on enhancing the emergency status, reinforcing the perception of refuge as a non-local, temporary phenomenon rather than a lasting aspect of a generally increased mobility amid our globally interconnected and crisis-prone world. In essence, the responsibility remains reactionary and leads back to the ethical debate differentiating between response and responsibility. Design initiatives in humanitarian aid, aiming to enhance refugee living conditions through shelter upgrades, risk imposing a 'global shelter imaginary' (Monk and Herscher 2021). This perpetuates a universal view of relief, blurring crisis and response distinctions and fostering specialized shelter production subfields.



Figure 2: Shigeru Ban’s Paper Log House in Kobe (Japan), 1995 and Better Shelter Initiative in Tanzania. Source: (Shigeru Ban Architects © Takanobu Sakuma, 2014 and Better Shelter Organization, 2023.)

2.3. The current European Union’s design policies

The official guidelines regarding asylum inside the European Union’s member states are regulated through the Common Approach to Asylum. In 2013, the EU member states reached a historic agreement on a unified asylum approach, influencing the design of refugee accommodations. The regulatory framework, articulated through the *Reception Conditions Directive*, aims to ensure 'decent' living conditions and enhance the 'self-reliance' of asylum seekers (EU Commission 2023). The legal concept of "standard of living" encompasses housing, food, employment, and care. The European Agency for Refugees (EUAA, formerly the European Asylum Support Office EASO) contributes to the concrete design of refugee accommodations by providing guidelines and design manuals for member states (EASO, 2016, 2019, EUAA 2021, 2022). Yet despite official policies, the member states grapple with asylum flows differentially, depending on their geographic position—whether as frontline arrival points or second-line destinations surrounded by safe third countries (Misselwitz 2010) and the actual situation for arriving asylum seekers varies. Particularly amid the unprecedented influx of migrants caused by the recent war events in Syria and Ukraine has prompted the assessments of member states' willingness to grant asylum. It seems the contemporary asylum dynamics serve as a strategy to counteract state intrusion, navigating the varied stances that states adopt based on their border situations and domestic political agendas.

Further, the guidelines cover five categories: Location, Allocation, Infrastructure, Security, and Design of Common Spaces. Each category begins with introductory statements and further details standards and indicators. For

example, the location category emphasizes effective access to services, specifying requirements like proximity to public services, schools, healthcare, and daily needs (EASO 2016). The standards section outlines details such as spatial organization, sanitary conditions, and sleeping quarters specifications. Some measurements, like a minimum height of 2.10 meters and minimum furniture requirements, are provided. The guide refrains from detailing construction or maintenance standards, referencing national and local standards based on geographical conditions. The infrastructure chapter specifies sleeping quarters, common areas, and facilities like washbasins, toilets, and showers. Requirements for separate bedrooms, minimum space per resident, and regulated access times are outlined. Overall, the guide seems to serve as a checklist for safety and quality parameters, including evacuation plans, natural ventilation, lighting, temperature, and noise protection.

The EUAA offers detailed design manuals, exemplified by 'Modular Design to Reception: Container Site Design,' providing practical insights for the construction of EU-standardized reception points (EUAA 2022). This comprehensive manual not only enumerates crucial functions for reception centers—such as registration, medical facilities, ongoing healthcare, administration, offices, security, and accommodation—but also juxtaposes practices, offering dos and don'ts through visualizations and renderings. Emphasizing an organic zoning system, the design principles propose a central 'nerve center' from which roads extend to accommodation zones and administrative areas, fostering an efficient and safety-oriented layout. Particular attention is dedicated to security (the seventh principle), advocating for staff presence, open environments for unobstructed views, and recommending fencing only when necessary for specific groups. The uniform layout guideline suggests using a standardized ISO 30 model of containers stacked on a maximum of two floors for residential purposes, with one sanitary container per floor. It's noteworthy that these official EU design manuals endorse standardized containers as a primary solution for reception point construction, aligning with a broader 'campization trend' observed across Europe (Kreichauf 2018). This trend manifests architecturally, functionally, and socio-spatially, leading to spaces where different aspects of asylum practice blur and social and cultural segregation may occur (Ebeling 2020).

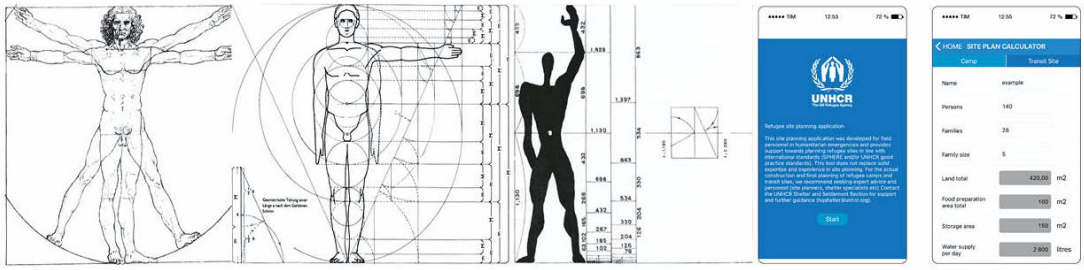


Figure 3: The assumption of a *model refugee*? Modern technology allows next to anyone the access to the widely established planning tools of UNHCR, some of its functions are depicted in these redrawn screenshots of the UNHCR refugee camp planning site. Source: (Collage by the author via © Britannica, 2023, © Neufert Stiftung, 2023, © Modulor, and © UNHCR Site Planning Tool, 2022.)

The establishment of a European model refugee and the full segregation of all spatial elements that surround asylum seekers by now seems complete (Figure 3). And, despite the UNHCR High Commissioner Filippo Grandi continuous reminder of refugees' dependence on the "generosity" of others (UNHCR 2022), European countries put a growing emphasis on a practice of asylum outside their territories and detention. Notably, the EU Parliament has endorsed the establishment of asylum check points and detention centers along the EU's external frontiers (European Parliament 2023), while the UK government currently advocates for asylum centers outside its territory (BBC 2024). This signifies yet another shift in the asylum practice, further alienating it from the design field of shelter or housing, seemingly deviating from the states' obligations outlined in the Geneva Declaration on the Rights of Refugees since 1951 (UNHCR, 1951), but it also aligns with a detected phenomenon that an increase in asylum seekers is followed by a tightening of laws (Kreichauf 2018).

3.0 ETHICS IN THE ABSENCE OF ETHICS

Inside the disputable creation of the highly controlled, so-called humanitarian space, what remains designers to engage with when it comes to care for refugees? When exploring the European spaces of asylum from a design-driven research perspective, the level of ethical engagement can be measured through a variety of factors such as attentiveness, responsibility, competence, and responsiveness (to the critical circumstances surrounding flight and refuge) (Tronto 2005). How to define a careful response to critical aspects like trauma, loss, language barrier? How to commit to safe and legal procedures and democratic decision making in asylum through design? It seems complex to detect one unique moral compass directing what has been put into practice by designers around the refugee architecture in the past decade, not only because the design approaches and constellations vary and tend to blur between the different group of actors – there are interventions based on private practice, those related to university-based initiatives, and lastly, projects put forward by the international development (Charlesworth 2014). The assessment of the value of an architectural contribution around the arrival of asylum seekers can follow those that mark any design typology, such as functionality, materiality, or sustainability. However, the fundamental value is formed through the perception and user experience of spaces (Hahn 2008).

In conjunction with the 2016 Architecture Biennale, which coincided with the influx of millions of Syrian refugees to Germany, the German Architecture Museum in Frankfurt (Deutsches Architektur Museum DAM), in collaboration

with design Studio Something Fantastic, curated the German Pavilion in Venice under the theme "Making Heimat – Germany, Arrival Country." Dedicated to embodying the spirit of welcome and reception for asylum seekers, the exhibition sought to explore the unique dynamics unfolding after the arrival of over a million displaced persons through a design lens. This included a focus on both newly built interventions and improvised solutions. Subsequent to the Biennale, DAM hosted an exhibition featuring an atlas of refugee architecture in Germany and neighboring countries like the Netherlands and Austria. The atlas showcased various examples of refugee accommodation deemed valuable from a design perspective (Schmal et al., 2017). The commitment to shaping ethical housing solutions was evident in diverse approaches and a variety of building types. The various solutions featured in the atlas range from temporary to more permanent solutions that allow for a flexible future use, exemplified in Figure 4.

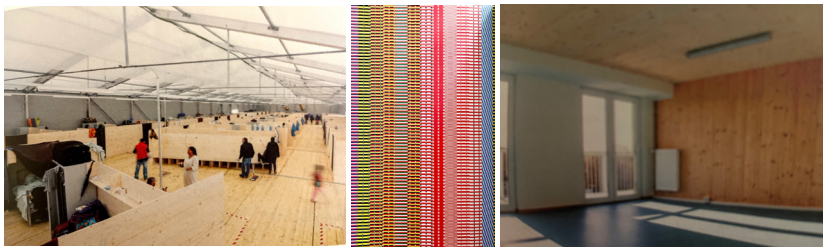


Figure 4: Collage made of images from the Refugee Atlas, Making Heimat, DAM, 2016. Source: (Author, 2023).

Revisiting the featured sites of the atlas a few years later, following another significant influx of refugees from Ukraine in 2023, provides an opportune moment for reassessing their contribution value, as noted by exhibition curator Oliver Elser.[2] Some reevaluations have unveiled discrepancies in the initial assumptions about optimal asylum design, particularly in cases where inhabitants' living patterns deviated from designers' expectations. For instance, spaces with abundant natural light and large windows, initially deemed atmospherically enriching, were, in some instances, covered with cardboard or shawls by inhabitants seeking increased privacy (Schmal, 2017). As with any typology, adaptation necessitates thorough evaluation, a profound understanding of users' living patterns and specific needs, and, inevitably, the passage of time. After all, there is no such thing as a model refugee.

Winston Churchill's renowned assertion, "First, we shape our buildings – then our buildings will shape us," from 1941 (UK Parliament, 2024), underscores the pivotal role of architecture in influencing our democratic understanding. Churchill fervently advocated for the reconstruction of the UK Parliament chamber following its complete destruction in WWII. Regarding the accommodation of asylum seekers and the limited access and knowledge designers have of specific needs, the ethical engagement of architects and designers in addressing the challenges of arrival and refuge in Europe can be viewed from an alternative perspective. Notably, institutions like the DAM, along with others, have initiated discourse and invested in research or installations to raise awareness, as seen in the report "Ingenmansland" (No-man's-land) by the Swedish Center for Architecture and Design in Stockholm.[3] Another instance is the installation "1.000.000 German Passports" in the Munich Museum of Architecture in the summer of 2023, critiquing asylum protocols and frontier practices, attracting numerous visitors.[4] Newly constructed designs addressing the plight of millions of refugees, such as Denmark's FLUGD, Refugee Museum situated in the former refugee camp in Oksbøl that once hosted millions of German refugees after WWII, represent a noteworthy endeavor (Figure 5). Executed by the prominent architectural firm BIG, this museum stands as a landmark in a relatively remote area, aligning with the vision to attract a broad audience and raise awareness on a topic often sidestepped or influenced by ongoing media debates and political trends. According to the director, a welcoming and distinctive architectural design plays a crucial role in achieving this.[5] Despite the pressing demand for housing stock that currently challenges cities and towns across Europe, fostering knowledge exchange remains central to the museum's mission.



Figure 5: Installation "1.000.000 German Passports" by Alfredo Jaar in Architecture Museum Munich, 2023 and FLUGD Denmark Refugee Museum. Source: (Author, 2023).

4.0 (ARRIVAL) ARCHITECTURE INTO THE UNKNOWN: HOUSING THOSE WHO WILL COME

An Irish Proverb says, "It is in the shelter of each other that we live."[6] – reminding us of the importance of never distinguishing between people when it comes to the argument of home. Housing is a fundamental human right (UN 1948) and whenever we are concerned the task, especially for an unknown user group, refugees and asylum seekers whose arrival date we don't know, it is important to make them an integral part of our society. If refugees are confined within humanitarian spaces, isolated from societal norms, the achievement of one of the key markers defining adequate housing—inclusion—will be elusive. Despite being a significant part of our society in terms of

numbers, they will remain secluded. If we consider architecture as a means of understanding our contemporary world, making the design realm surrounding arrival more meaningful and humane requires further contemplation of an "arrival architecture" into the unknown.

What ultimately constitutes a home? It lies in how we appropriate and adapt the spaces we inhabit to our individual needs. Regardless of how well a designer anticipates the use of walls and floor layouts in a spatial container, they merely suggest possibilities to the user. The poetics of home reside in multifaceted layers shaped by individual cultural, social, and aesthetic preferences, limited or enriched by resources and creativity. Observing the modifications in housing and refugee accommodations reveals what we could term the *poetics of living*. In this context, it seems only natural to note how swiftly refugees transform basic relief structures provided to them in emergencies, adapting to host essential activities for their livelihood. The informal layer enhances and adds value to standardized design forms, where the spatial container serves as the shell within which actual life unfolds. The adaptive power and creative energy exhibited by displaced individuals globally take distinctive and striking forms. Beyond well-known examples, like the refugee church in the Calais camp, crafted by the Eritrean and Ethiopian refugee community, similar adaptations occur daily within humanitarian spaces worldwide, using whatever materials are available (Figure 6).



Figure 6: Images of the Calais Refugee Church. Source: (Jerome Sessini. *FRANCE. Calais. November 27, 2015*. https://jstor.org/stable/community.18991316 and https://jstor.org/stable/community..18991326.)

While some larger-scale self-crafted structures, such as the Calais church, exist, smaller-scale adaptations are common, especially where the provided spatial container lacks the poetic essence of living, as seen in container sites – the prevalent structures for reception and accommodation in Europe. Despite criticisms of container solutions, like the "Tempohomes" in Berlin, single-story rows of container apartments forming small villages in urban patterns (Parsloe 2020), inhabitants report an atmosphere akin to suburban residential neighborhoods, with individual adaptation efforts, from interior modifications to gardening interventions, contributing to a positive reception (Figure 7).[7]

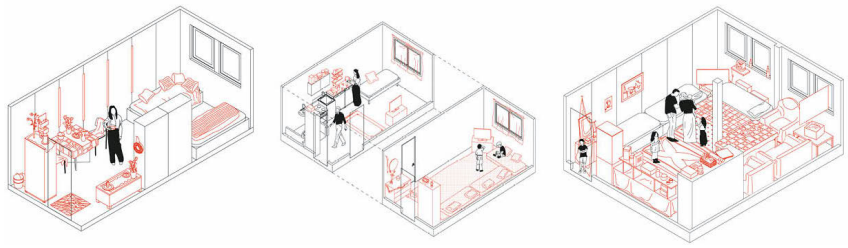


Figure 7: Redrawing of adaptation processes inside various Tempohomes in Berlin, studied by architecture students of TU Berlin. Source: (Misselwitz, P. et. al., 2022. T*empohomes – Untersuchung sozial-räumlicher Aneignungspraktiken von Geflüchteten in ausgewählten Berliner Gemeinschaftsunterkünften.* Berlin: TU Berlin Verlag.)

CONCLUSION

While numerous designers soke to engage with the design around asylum applying their interpretation of moral codes across time, there are complex regulations restraining contemporary interventions as well as (partly unconscious) design biases that lead to counterproductive design effects for users. If designers remain unable to dissolve the humanitarian space into the shared urban space, in this sense, the informal sphere of design that is informed by everyday life activities, regardless of the respective spatial container or resource scarcity, could become a critical factor. It is imperative to acknowledge this when discussing an innovative approach to arrival architecture into the unknown. Innovation, therefore, could require the readiness of the designer to shift from designing even more to a mediating role between users and policy makers, potentially, a more experimental or supportive role when it comes to design. Another scenario, would embrace the temporary state as permanent scenario, embedding refugee housing in any form of housing typology and understand it as an integral part of our contemporary urban coexistence from an architectural point of view. When we contrast the different design philosophies around the accommodation of asylum seekers across time. For instance, the spatial configuration of the Tempohome container villages in Berlin showcases strong resemblances with some of Ernst May's settlements in Silesia – with the difference that the Tempohomes container units have short life expectancy and operate on short term, emergency building permits while some of Mays designs are still in use.



Figure 8: Contrasting the designs for refugee settlement of Ernst May during the inter-war period in Europe with the Belin Tempohomes reveals striking resemblances, just that the duration of the container sites is limited and made of temporary units, while May's designs from that time, in some cases, are still in use. Source: (Ernst May Gesellschaft, 2023 the author, 2023.)

It feels safe to say that any design speculations around the architecture of arrival, has to stem from those elements: the informal sphere and the support of invisible design actants, combined with the consideration of the aspects of time and the temporality in the sense of not considering any form of housing solution outside the general communal housing stock. This seems ever more urgent in an increasingly mobile population where migration for improved work and living conditions is common (IOM, 2024). In this sense, some of the older designs of arrival architectures, that combine not only the features of short-term stay, but the chance for a permanent homes, remain the most ethical way of approaching refugee housing and, could therefore be considered a moral compass for any design interventions, particularly towards urban stimuli in the further development of the European metropolitan regions.

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ENDNOTES

[1] Foucault defines heterotopia(n places) as "other places", externally to the state of normal. They are reserved for people who find themselves in moment of crisis, or who have in other ways deviated from the societal norms.

[2] Telephone interview with DAM curator Oliver Elser via phone, conducted by the author, 13 October 2023.

[3] On site interview with FLUGD research lead Stina Troltdroft Andersen on site in Oksøl, 23 August 2023 and FLUGD museum director Claus Kjeld Jensen via phone, conducted by the author, 16 October 2023.

[4] *Ingenmansland* (= No-man's-land) is the title of a report on the feasibility of the reception facilities for asylum seekers in Sweden in 2022, commissioned by ARKDES, the Museum for Architecture and Design in Stockholm. The report marks a journey to and survey of the places that accommodate and service refugees in Sweden, drawing comparisons from the recent experiences of the 2022 Ukraine crisis to the situation after the influx of refugees from Syria in 2015 through site visits and interviews with protagonists involved.

[5] On site interview with exhibition curator and museum director Andreas Lepik, 14 August 2023.

[6] Irish Proverb, see, among others: p. 25 in Christine G.T. Ho, Loucky James. Humane Migration: Establishing Legitimacy and Rights for Displaced People. West Hartfourd: Kumarian Press, 2012.

[5] On site interview with facility managers and press spokeman of Landesamt für Flüchtlingsangelegenheiten LAF, 14 August 2023.

Forced Labor in Building Material Supply Chains – Evaluating Risk in Specifying Architectural Materials

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ABSTRACT: This paper investigates the presence of forced labor in the supply chain of materials used in the design, construction, and delivery of buildings. While the Architecture, Engineering, and Construction (AEC) industry has conclusively acknowledged the very real costs of climate change, it has addressed the impacts of coercive labor practices and modern-day slavery in the making of buildings with far less commitment. This paper seeks to redress the situation by activating three research questions: how might we identify a common language in service to recognizing forced labor, what are available tools and sources currently at our disposal for addressing the problem, and what lessons can one learn from a case study that localizes the risk of forced labor in imported building products to the United States? In response, this paper identifies an internationally sanctioned vocabulary whose terms and definitions can help the building industry better characterize instances of forced labor while offering a critical review of currently available tools, protocols, and data resources of possible use to the industry. Whether in extracting raw materials, manufacturing building products, installing said products, or disposing of them as waste at the end of life, the health and safety of workers associated with building remain imperiled. As this reality can no longer be denied, this paper recognizes three aspects of a possible solution space, all the while remaining critical when confronted with the reality of forced labor as a deeply entrenched problem in the industry.

KEYWORDS: forced Labor, building material supply chains, architectural materials, auditing risk

1.0 DEFINITIONS AND TYPES OF FORCED LABOR

What is meant by ‘forced labor’ and in what ways do we encounter it in the supply chain of building materials and construction sites? This paper communicates the findings of a resources review on the subject seeking documentation published by governmental and para-governmental bodies, non-governmental agencies (NGOs), researchers, and members of the AEC industry who have sought to identify the evidence of, and remedies for, human rights violations (including forced labor) in the building industry.

1.1 Naming the problem

Is there a shared, operational definition of the unlawful practice that is ‘forced labor’? Is there a consensus on what it is, how to identify it, and how big is the problem? This paper introduces the AEC industry to an internationally sanctioned vocabulary whose terms and definitions help to identify, characterize, and address instances of forced labor. Governments, para-governmental bodies, non-governmental agencies (NGOs), labor unions, and academic researchers agree on clear and unambiguous definitions of what constitutes forced labor including its various guises and appearances. Before defining forced labor, however, this paper recognizes four major sites where workers are at risk of being imperiled in the building industry. The first includes all locations where material extraction takes place, as all building materials begin their life during a process of removal from the ground, be they fossil fuels, stones, or wood. The second is the concatenated network of manufacturing enterprises whose factories produce tens of thousands of building products typically installed by other workers on building sites. The third is the building site itself whose laborers are contract-hired or recruited for the duration of their process of the project. The fourth and final site is that of waste, wherein refuse yards become the dumping grounds of all non-recycled content resulting from the demolition of buildings. For reasons of scope and limited access to data, this paper addresses primarily questions of supply chain transparency in manufacturing.

According to the International Labour Organization (ILO)–a United Nations (UN) agency whose members include representatives from national governments, employers, and laborer organizations—tasked with setting labor standards for decent working conditions, forced labor includes

> all work or service which is exacted from any person under the menace of any penalty and for which the said person has not offered [themself] voluntarily. (Ruwanpura and Rai 2004; International Labour Office 1930).

All work whose fruits are destined for someone other than the person who labors, not freely chosen and imposed under threat or intimidation is considered forced labor. At the highest risk of which are impoverished and disadvantaged citizens, migrant workers, precarious peoples, women, and children. According to the ILO, there are eleven indicators of forced labor, including abuse, deception, restriction of movement, isolation, physical and sexual violence, intimidation and threats, confiscation of state-issued documents (passports, identity cards), wage withholding, debt bondage, poor working and living conditions, and excessive overtime (International Labour Office n.d.a.).

In the building industry, forced labor also takes the form of unpaid work or payment for work that is less than

originally promised, required recruitment fees paid to employer or third-party agents, child labor, work that is subject to the rules of Kafala, forced migration or relocation for work, forced participation in non-work related activities, unhealthy and unsafe exterior working conditions, restricted right to self-assembly, psychological or physical coercion, and not being able to communicate one's concerns to independent third parties. Moreover, it is unlawful that member organizations use forced labor as

> as a means of political coercion or … or as a punishment for holding or expressing political views ... ideologically opposed to … established … systems," or "as a means of racial, social, national or religious discrimination (International Labour Office 1957).

According to the UN, *Universal Declaration of Human Rights* ratified in December 1948, as many as five separate articles speak to forced labor. Article 4, for example, acknowledges the basic human right that "no one shall be held in slavery or servitude" (United Nations 1948). Article 13 identifies that "everyone has the right to freedom of movement and residence within the borders of each state" as well as "everyone has the right to leave any country, including his own, and to return to his country"; an important article in the context of labor-based migration that accompanies the search for work on building sites. Article 20 states that "everyone has the right to freedom of peaceful assembly and association"; a human right that is often in question when laborers are punished for wishing to self-organize or unionize. Article 23 is the most explicit relative to labor rights, noting that everyone has the,

> right to work, to free choice of employment, to just and favorable conditions of work, … to equal pay for equal work, … to just and favorable remuneration, … [and] to form and to join trade unions for the protection of his interests (United Nations 1948).

Numerous ILO guidelines and standards exist for ameliorating the status of workers in the building industry (International Labour Organization n.d.), even as they recognize the heightened precarity of Indigenous peoples, dock workers, fishers, seafarers, domestic workers, mothers, and children. Convention C029 - Forced Labour Convention, 1930 (No. 29) addresses forced labor directly, noting that the "illegal exaction of forced or compulsory labour shall be punishable as a penal offence." (International Labour Organization 1930). Lastly, in 1998, with increasing pressures to recognize the growing liberation of labor and the global reach of corporate supply chains, the ILO adopted the 1998 "ILO Declaration on Fundamental Principles and Rights at Work" which all member states are subject to. Its fundamental tenets are:

> freedom of association, …right to collective bargaining; the elimination of all forms of forced and compulsory labour; … abolition of child labour; … elimination of discrimination…; [and, the right] to a safe and healthy working environment (International Labour Organization 2022).[1]

Eradicating forced labor is also a tenet central to the goals of the UN 2030 Agenda for Sustainable Development. As outlined in Sustainability Goal # 8, eradicating poverty and achieving a better standard of living for all requires we "promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all."(United Nations n.d., 8) In this, we must,

> take immediate and effective measures to eradicate forced labor, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labor, including recruitment and use of child soldiers (United Nations n.d., 8.5).

Wherever necessary, direct actions should "protect labor rights and promote safe and secure working environments for all workers." (United Nations n.d., 8.6). In addition, the UN's "Guiding Principles on Business and Human Rights," sanctioned by the UN Human Rights Council in 2011, calls upon all businesses to "Protect, Respect and Remedy" the human rights of those they employ in the process of conducting business and seeking to maximize profits (Office of the United Nations High Commissioner for Human Rights 2011). Nation-states are responsible for protecting the rights of those who labor in their countries; so too must businesses ensure that labor rights are respected in the course of doing business. The UN's "Guiding Principles" are voluntarily adopted by companies that seek to establish a competitive advantage by way of social awareness. Corporate audits, certifications, and due diligence in the procurement of goods and services that ensure slavery-free supply chains across all tiers of a company's procurement profile are the gold standard of ethical business. The contribution these processes make to increasing our awareness of forced labor is addressed in Part 2.0.

With specific reference to the AEC industry, the ILO acts as an information convener and conduit for international labor unions such as the Building and Wood Worker's International (BWI bwint.org), UITBB (*Union internationale des syndicats des travailleurs du bâtiment, du bois et des matériaux de construction*, uitbb.org), and contractor organizations including the Confederation of International Contractors' Associations (CICA, cica.net), the European Construction Industry Federation (FIEC, fiec.eu), the International Federation of Asia and Western Pacific Contractors' Associations (IFAWPCA, ifawpca.com), The Associated General Contractors of America (AGC, agc.org), and the Canadian Construction Association (CCA, cca-acc.com).

1.2. Locating the problem

How bad is the problem of forced labour in the building industry? According to the 2023 "Global Slavery Index" by the Australia-based non-profit 'Walk Free,' "twenty-eight million people are subject to forced labor with the highest incidences in North Korea, Saudi Arabia, Turkey, UAE, and Russia (Walk Free 2023). The monetary value of this illegal activity in modern slavery, and of importing "at-risk" goods for countries in the G20 is in the billions. The ILO claims that close to 25 million people are at risk of forced labour, the greatest number of whom (83%) labor in the private sector, resulting in billions of dollars of profits garnered illegally (International Labour Organization n.d.b.) Moreover, 4 million people experience forced labour at the hands of governments and state actors (International Labour Organization n.d.b.).

According to Human Rights Watch (HRW)—an NGO whose lawyers, journalists, policy analysts, and on- the-ground observers monitor human rights abuses across the world, collecting front-line data and personal narratives—injustices in the building industry continue to impact the lives of millions. Captured in their report from 2006, "Building

Towers, Cheating Workers, Exploitation of Migrant Construction Workers in the United Arab Emirates" five hundred thousand migrant construction workers were subject to life-threatening working conditions. As stated by HRW, "behind the glitter and luxury" that is modern Dubai are the hardships of migrant construction workers who,

> present a much less attractive picture of wage exploitation, indebtedness to unscrupulous recruiters, and working conditions that are hazardous to the point of being deadly (Human Rights Watch 2006).

In their 2017 report, "Qatar: Take Urgent Action to Protect Construction Workers, FIFA, National Associations Should Press Qatar on Heat Risks, Preventable Deaths," HRW alerted the world to workers at risk of heat stroke and related cardiac arrest (Human Rights Watch 2017). And in 2012, HRW published "Building a Better World Cup, Protecting Migrant Workers in Qatar Ahead of FIFA 2022," a 150-page report that forecasted the labor-based exploitation of the more than a million workers who migrated to Qatar to build the infrastructure for the 2022 World CUP (Human Rights Watch 2012). At the very center of this was the severely compromised process of recruiting said workers wherein male workers originating from southeast Asia (India, Pakistan, Bangladesh, and Nepal) were required to pay exorbitant recruiting fees to agents in the thousands of dollars, indebting themselves and imperiling their lives and those of their families for years. The subject of recruitment fees and the role they play in signaling possible human rights abuses in the building industry is the subject of an audit tool discussed in Part 2.0 of this paper.

According to 'Walk Free,' the United States could import close to 170 million dollars of forced labor products, while Germany could import as much as 44 million dollars in slavery-tainted electronics, solar panels, textiles, and timber, a good deal of which is destined for the building industry. In the face of such staggering numbers, what are the currently available tools, protocols, and data resources of possible use to the industry to help it evaluate its exposure risk to forced labor (Walk Free 2023)?

2.0 AVAILABLE TOOLS AND DATA RESOURCES: LAWS, DATA, AND INVESTIGATIVE REPORTING

The human rights community, labor organizations, affiliated NGOs, software companies, business auditors, and academics are active in collecting and reviewing first-person narratives, business-centered certifications, databases, and algorithmic tools for evaluating the business risk of forced labor in material supply chains, contributing to our growing awareness of the problem both quantitatively and qualitatively. Researchers and professionals in the AEC industry are identifying operational tools, protocols, and data sources for evaluating the risk of forced labor in construction. These process-ready resources are identified in this paper as legislative, business-centered, and investigative, in origin. Legislative resources are those produced by national governments in response to global threats and in service to their citizenry. National laws limit and constrain an industry's global procurement reach by prohibiting the importation of products manufactured using forced labor. Business-centered tools are those aligned with industry certifications, due diligence protocols, and supply chain audits. While these are typically deployed when studying supply chains for garments, cars, and electronics, the hope is that they can be of use to the building industry. These databases and digital query protocols are implementable for a restricted set of building materials with a limited number of production tiers. And where business-level tools fall short, this paper introduces investigative reporting and on-the-ground evidence-based information gathering by human rights organizations and citizen journalists, as a third and final category (Jurrat 2011).

2.1 National legislation

The United States, the United Kingdom, and the European Union all have laws and guidelines governing forced labor in the material supply chain of products sold in their respective countries (Fanou 2023).

In the United States, Customs and Border Protection (CBP) has the legal right to enforce the confiscation of imported goods at their point of entry, allegedly produced using forced labor (United States Customs and Border Patrol n.d.). Subscribing to the ILO and UN definition of forced labor, the US CBP seizes goods in shipments entering the country if believed to have been produced illegally. In "implement[ing] Section 307 of the Tariff Act of 1930 (19 U.S.C. §1307)," CBP has the power to issue a Withhold Release Order (WRO), that identifies suspected products. The law states that,

> all goods, wares, articles, and merchandise mined, produced, or manufactured wholly or in part in any foreign country by convict labor or/and forced labor or/and indentured labor under penal sanctions shall not be entitled to entry at any of the ports of the United States (United States Congress 2021).

The United Kingdom (UK) passed a 'Modern Slavery Act' in 2015 to enforce, charge, and prosecute those charged with modern slavery, as well as to compensate those victimized by the crime. The Act

> requires businesses over a certain size to disclose each year what action they have taken to ensure there is no modern slavery in their business or supply chains (United Kingdom 2015).

Different from the US, the UK acknowledges that a significant degree of forced labor is found in the UK. According to The Guardian, as many as thirteen thousand people are enslaved in the UK in the sectors of "agriculture, hospitality, fishing, private homes, brothels, nail bars and cannabis farms (Kelley 2015)." According to an AEC industry report by the Chartered Institute of Building "Construction and the Modern Slavery Act, Tackling Exploitation in the UK," forced labor in the building industry has been noted in physically strenuous jobs such as laying of driveways, property repairs, building demolition, block paving, and waste recycling (Chartered Institute of Building 2018).

In 2021, the European Union (EU) issued its "Guidance" to conduct "Due Diligence" reviews of forced labor risk in the material supply chains of products (European Union 2023). Even if non-binding and hence unenforceable by law, the Guidance establishes a:

> framework to investigate the use of forced labour in companies' supply chains. If it is proven that a company has used forced labour, all import and export of the related goods would be halted at the EU's borders and companies would also have to withdraw goods that have already reached the EU market (European Union 2023).

Moreover, as part of the EU's 'Directive on Corporate Sustainability Due Diligence', aspects of human rights (including labour rights and justice) are considered alongside questions of environmental sustainability (European Commission n.d.). Whether the EU will pass legislation ensuring more robust and rigorous enforcement remains to be seen (Vanderford 2022). While the legislative power of national governments is essential in the space of human rights, encouraging and incentivizing voluntary changes and the best business practices is also important.

2.2 Business-centered tools and data: certifications, supply chain auditing, and social LCA.

This paper discusses three categories of business-centered tools and resources for evaluating forced labor risks in the building industry: certifications, supply chain auditing, and social LCA.

Business-centered industry certifications are now essential for the business of sustainability, so too can they be for forced labor. Certifications facilitate information gathering, professional awareness, and industry peer review of best practices. The long list of third-party certifications associated with sustainability only continues to grow with every passing year: BREEAM, LEED, WELL Building Standard, Green Globes, ENERGY STAR, PASSIVE HOUSE, CASSBEE, GREENGAURD, Cradle to Cradle are but a few (Vierra n.d.). Indeed, the industry is ever more aware of the need to measure the performance of its environmental claims, even while inundated with assessment tools whose data is rarely interoperable or comparable. In the end, the continued fragmentation of sustainability audits undermines the goals of sustainability. How might this be avoided in the context of forced labor audits? In 2022, John Russell Beaumont of COOKFOX Architects published the "Survey of Labor Certificates for the Built Environment." This 36-page report identifies available business tools for evaluating the risk of forced labor in building material supply chains. In reviewing fifty current certifications, findings are communicated via a matrix that indicates the presence of client input, member network, survey, field inspections, remote research, automated, public records, regional risk, and tiered analysis (Beaumont 2022). Beaumont identifies three main categories of certifications: Supply Chain Management (SCM) evaluations, Supplier Certifications, and Independent Evaluations. SCM involves the introduction of proprietary third-party services for analyzing the steps in a company's supply chain for facilitating 'Due Diligence' reporting and compliance with various 'Modern Slavery Acts.' Supplier Certifications typically originate from within industry groups to ensure greater transparency and sales confidence. Lastly, Independent Evaluations are those made by non-business related, non-profit organizations including The Walk Free organization with its Global Slavery Index, the KnowTheChain Benchmark Methodology common in the garment industry, and the Trafficking in Persons Report issued by the US government. The COOKFOX "Survey of Labor Certificates" is the first of its kind, and an essential resource for the AEC.

Supply chain auditing is a distinct feature of certifications that facilitate the identification of measurable and verifiable data. However, while business entities charged with (repeatedly) manufacturing the same product have greater access to the supply chain of said products, sub-contractors, builders, engineers, and architects are several 'tiers' removed from product manufacturing. This makes the auditing, evaluating, and remedying of instances of forced labor in the building industry more complex. It is primarily as informed consumers that members of the AEC industry have leverage during this process. In the same way that I may choose not to purchase branded gear because they've been cited at high risk for forced labor in their material supply chains, so too I might refrain from specifying suppliers of concrete, wood, stone, and aluminum. AEC members are actively reviewing auditing interfaces commonly used for general manufacturing for possible compatibility with the building industry, even as important differences exist. While some third-party auditors collect self-reported information, others employ independent on-the-ground observers; while some conduct 'desk audits' to corroborate company claims, and others deploy algorithms to automate the monitoring (Beaumont 2022). AEC professionals of the Design for Freedom (DFF) Working Group at Grace Farms, of which I am a part, are involved in an information-gathering project that investigates more than a dozen third-party auditing platforms for possible data interoperability in service to a shared culture of Environmental, Social, and Corporate Governance (ESG) management and compliance (Grace Farms Foundation 2022). During an interview with a Verité director, the enormity of the task of auditing forced labor risks in the building industry was notable. Not only is it difficult to get access to front-line laborers in Tier 3 and 4 companies, but it is even more complicated when this level of analysis is required for products that are used only once in a singular building project. How difficult is it to map the material supply chain for a be-spoke building envelope commissioned for Dubai, and designed in New York City? In response, Verité offers two separate tools. The 'Responsible Sourcing Tool (RST)' (responsiblesourcingtool.org) was created following the passing of US federal acquisition regulation that requires all government contracts for building overseas to ensure its contractors submit an anti-trafficking plan. The second tool Verité is involved with is CUMULUS (verite.org/cumulus), a digital interface compliance tool focused on recruitment fees as the key indicator of forced labor. Predicated on the hypothesis that if a worker is forced to pay fees for being hired, this is a clear sign that they will be at risk for forced labor. When CUMULUS investigates a particular company for its recruitment practices, it requests that the company submit receipts in evidence that they paid for recruiting their workers. If workers are burdened with this cost, this is only the first of many possible injustices. This information-gathering project is still underway, a full review of AEC auditing mechanisms will be reported with findings and conclusions forthcoming.

Social LCA is the third tool at our disposal. As previously noted, sustainable design and construction have already contributed important resources of use for those committed to measuring forced labor risks in the building industry. One such resource is the 'accounting' infrastructure identified with building-centered Life Cycle Assessments. In the same way that environmentally contingent metrics can be rigorously connected with many aspects of a building's supply chain, so too can worker welfare be quantitatively measured to enrich the definition and practice of LCA. According to the United Nations Environment Program (UNEP), Social Life Cycle Assessments (S-LCA) capture important qualitative stakeholder and community-based values, observations, and evidence of lived inequalities that

would otherwise be lost when only reviewing the material and energy expenditures of supply chains (Life Cycle Initiative, UNEP and Social Alliance 2021). Of the five different stakeholder voices considered in S-LCA, worker rights are included alongside those of the local community, value chain actors, consumers, and society (Life Cycle Initiative, UNEP and Social Alliance 2021). UNEP S-LCA includes topics such as,

> Freedom of association and collective bargaining, Fair salary, Forced Labor, Equal opportunities/discrimination, Health and safety, Social benefits/social security, and sexual harassment (Life Cycle Initiative, UNEP, and Social Alliance 2020).

Including socially determined variables when calculating lifecycle assessment is a promising source for quantitative information on labor practices. This does, however, require a significant investment in the collection of on-the-ground verifiable data. Building material supply chain certifications, audits, and S-LCA tools help us measure the risk of forced labor in the AEC. Conversely, they are not always effective for identifying critical hotspots whose conditions are not measurable using business-centered tools. The remainder of this paper introduces the first outlines of a case study in which identifying instances of forced labor in the material supply chain of composite material building products struggles in the face of certifications, audits, and S-LCA tools.

CONCLUSION

This paper argues for addressing the presence of forced labor in the supply chain of building materials. It identifies the vocabulary of an internationally sanctioned common language for naming, recognizing, and remedying forced labor. It reviews currently available tools, protocols, and data resources of possible use to industry. Whether in extracting raw materials, manufacturing building products, installing said products, or disposing of building waste at the end of life, the health and safety of workers associated with building remain imperiled. As this reality can no longer be denied, this paper recognizes the beginnings of a possible solution space, notwithstanding it adopts a critical position vis a vis the impact of business-centered tools when confronted with the reality that forced labor is a deeply entrenched problem in the industry.

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ENDNOTES

1 For a critique of the 1998 Declaration, see (Alston 2004)

Architecture Washing: A Framework for Investigating Human Rights Abuses in the AEC

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ABSTRACT: This paper identifies, names, and characterizes the practice that is ‘architecture washing’ as present in the Architecture, Engineering, and Construction (AEC) industry to demonstrate that when and where it occurs, ‘architecture washing’ detrimentally impacts the industry, the quality of our built environment, and society at large. The content addressed in this paper includes a working definition of ‘architecture washing, a body of academic research associated with human rights abuses in the built environment centered on forced labor, an analysis of the more established practice of ‘greenwashing’ as a possible model for ‘architecture washing’, and the outline of a framework for investigating the probability of ‘architecture washing’ on any given project. In so doing, it offers a framework for recognizing some of the material, economic, social, and political conditions that encourage its deployment, mechanisms intentionally designed to render AEC participants complicit, and key characteristics in a project’s delivery process that exposes said project to a high probability for ‘architecture washing’.

KEYWORDS: architecture washing, forced labor, human rights abuses, AEC industry

1.0 ARCHITECTURE WASHING, WHAT IS IT, AND WHY IT IS IMPORTANT?

This paper identifies, names, and characterizes the practice that is ‘architecture washing’ as experienced in the Architecture, Engineering, and Construction (AEC) industry to demonstrate that when and where it occurs, ‘architecture washing’ detrimentally impacts the industry, the quality of our built environment, and society at large. Ample evidence of contemporary examples of ‘architecture washing’ are discussed to indicate its currency and extent. In addition, this paper offers a framework for recognizing material, economic, social, and political conditions that encourage its deployment, mechanisms intentionally designed to render AEC participants complicit, and key characteristics in a project’s delivery process that exposes said project to a high probability for ‘architecture washing’.

But what is ‘architecture washing’? Quite simply, it is the deployment of building design and infrastructure projects as forms of spectacle for cleansing—that is, ameliorating—the reputation of those who commission them. Architecture washing occurs when building projects are used to rehabilitate the public image and/or financial standing of governmental (legislative, judiciary, and extra-judiciary), para-governmental, corporate, and private entities. This act of ‘purification’, aimed at benefiting clients, patrons, and investors, seeks to avert attention from possible wrongdoing, silence one's opponents, and distract from rule of law violations. Implied in the very act of building is the power and strength needed to marshal all the material and energy resources with which architecture defies gravity. However, when authority and influence co-opt the practices of design, engineering, and construction, to validate, certify, and celebrate without question or critique, we are witness to ‘architecture washing’. Laundering, cleansing, rehabilitating, and purifying the political, reputational, and financial standing of those who commission said projects and who possess the ‘strength’ to build is its very goal.

An essential characteristic of most forms of ‘washing’—be it ‘green’, ‘sports’, or ‘architecture’—is that the power of projection—be it in social media, international relations, or economic forums—is held, disproportionately, by state, corporate, or institutional players. They set the agenda, construct the language, dictate the terms, and lay claim to evidence. In the face of such vast expenditures of human effort and financial investments, those who dare allege unethical, corrupt, and illegal activities are swiftly challenged. Commissioning ‘impressive’ works of architecture persuades and influences public opinion. Indeed, nation-states routinely harness large-scale building projects for bolstering morale, strengthening national identity, and fortifying regimes. Projects conceived at an international scale for advancing national interests are planned, bid, and constructed to attract investment, revitalize state pride, and bolster political might. Vast transformations to the built environment are made precisely for their global impact, international acclaim, and self-evident value. Yet, they don’t always partake in ‘architecture washing.’

When they do, they are at a much higher risk of perpetuating social injustices, state crimes, and human rights abuses. When buildings are used to distract, they silence opposition, finance misinformation, and render their makers complicit. In this, the AEC industry is called upon to recognize how the commissioning, promotion, design, engineering, and construction of large-scale signature projects are practices that place its members at risk. All who labor in the AEC industry and who partake in ‘architecture washing’ implicitly underwrite the social harms, which include but are not limited to disempowering a workforce, forced migration, inhuman working conditions, modern slavery, and environmental degradation. How, therefore, might we better recognize the material, economic, social, and political conditions that precipitate the presence of ‘architecture washing’? What are the various mechanisms

that are expressly designed to facilitate its complicity? And what are identifiable characteristics, or signs that indicate that a project is at a higher risk of succumbing to its practices?

These questions are addressed in this paper whose various sections: (1.0) contribute a working definition of 'architecture washing; (2.0) identify a body of academic research associated with human rights abuses in the built environment that includes forced labor on building sites and in material supply chains; (3.0) evaluate the more established practice of 'greenwashing' as a possible model for 'architecture washing'; (4.0) outline an initial research-based framework for investigating the presence of 'architecture washing' on any given project; and (5.0) introduce the NEOM project in Saudi Arabia as a case study for testing said framework.

2.0 LITERATURE REVIEW, FORCED LABOR INDICATOR

Where and how does 'architecture washing' exist in the AEC industry? To help answer this question, I turn to a larger body of scholarship associated with human rights abuses in contemporary building practice, wherein we are better able to locate key indicators of said 'washing.' Moreover, 'social sustainability' is a principle of care that offers the AEC industry a vastly more integrated definition of sustainability, in recognizing that design and construction directly impact the social conditions of building users, construction site laborers, material producers, and their larger communities.[1] Indeed, at times, these conditions contribute to placing individuals at a higher risk of precarity, risk, and peril; as happens, for example, when design neglects to factor in rising sea levels placing residents of low-lying areas at serious exposure to flooding and death, when engineering encourages the use of inexpensive resins in manufactured materials that thereafter prove to be toxic, or when project managers allow sub-subcontractors to charge migrant workers recruitment fees for working on their projects. All of these are instances wherein the delivery of building projects endangers the lives and safety of others. The social risk indicator that I have identified as most indicative of projects at a higher risk of 'architecture washing' is that of 'forced labor'. A comprehensive literature review focused on the occurrence of forced labor in the building industry has corroborated a clear link between a compromised set of labor practices and 'architecture washing'. Projects identified with forced labor on their building sites and/or in their material supply chains were invariably at greater risk of 'architecture washing'. High-profile international gatherings such as the Olympic Games (Beijing Summer 2008, Sochi Winter 2014, Rio de Janeiro Summer 2016, Beijing Winter 2022) and FIFA World Cups (Brazil 2014, Russia 2018, and Qatar 2022) were most representative of the dual-risk of forced labor and architecture washing.[2] Invariably, events with non-negotiable deadlines encourage vast monetary expenditures by states, institutions, corporate sponsors, and private investors who bank on their global reach and projected financial returns. What is drowned out by the glitz and glam, however, is the increased risk of human rights abuses occasioned by such events.

This was the fate of several building projects associated with the 2022 FIFA World Cup held in the Gulf State of Qatar.[3] For more than seven years, this part of the world witnessed unprecedented construction activity that included multiple stadia, large scale infrastructure including bridges and dams, luxury housing estates, recreational centers, and extensive commercial corridors. Yet, all this feverish building activity was predicated on the exploitation of a migrant population of nearly two and half million laborers, "an estimated 88.4 percent of the small gulf nation's population."[4] According to Human Rights Watch (HRW), 95% of the country's work force is comprised of migrant laborers, of which one million are involved in construction.[5] The result being sociologists, political scientists, economists, anthropologists, medical doctors, engineers, NGOs, and journalists have all documented clear evidence of human suffering in Qatar's building programs. As early as 2016, the predicament of laborers on FIFA related construction sites was brought to international attention when both working and living conditions were the subject of a public awareness campaign by investigative journalists from Amnesty International and *The Guardian*.[6] While UN bodies and NGOs, such as the International Labour Organization (ILO), Human Rights Watch (HRW), and Amnesty International (AI), captured the world's attention with published reports of firsthand worker testimonials.[7] Independent scholars the likes of urban and labor theorist Natasha Iskander, furthered informed us of the underlying conditions which precipitated the vulnerability of those tasked with building the world's playground, that was Qatar 2022.[8]

Migrant laborers who travelled from as far as Nepal, India, Bangladesh, and the Philippines were subjected to serious hardships.[9] Basic worker rights were curtailed, be this in the form of delayed or unpaid wages,[10] not having access to protective work gear,[11] working in excessive heat and sandstorms,[12] having contract conditions misrepresented,[13] being subject to debt bondage,[14] and having to wait inordinately long for civil proceedings, when available.[15] Both on and off the construction site, laborers dealt with serious challenges to their health and well-being. Housing for most migrant workers was inadequate, unsanitary and unhygienic.[16] For many, nutrition was inadequate;[17] they were deprived of sleep[18] and unable to access medical assistance.[19] At times, laborers had no personal freedom to leave the site and/or living compounds, and with their right of movement seriously curtailed, the comings and goings of workers were tracked.[20] This was certainly the case when laborers had their passports withheld upon arrival.[21] Even more egregious, were risks to personal safety both on and off the building site, with laborers subjected to verbal abuse,[22] sexual harassment,[23] and even death.[24] By the end of 2016, the Qatari government and companies involved in the construction of its various building sites were called to account. It could no longer be denied that construction sites in a country readying itself to receive a global audience were subject to human trafficking, dangerous working conditions, and physical abuse. With ever more evidence mounting, the State of Qatar agreed to establish a legal task force. Following the publication of its independent report commissioned from the international law firm, DLA Piper, claims of increased compliance and auditing were made by Qatari officials to placate some of the most serious concerns.[25] New housing was built, and workers were offered better working conditions. However, repeated calls for overhauling, if not eliminating, the incredibly punitive legal regime that is Qatar's Kafala system went unheeded.

In essence, Qatar and its various legal surrogates drowned out their critiques with abundant counter-narratives in the press and with carefully deployed diversionary tactics that included shepherding international reporters to visit newly built dormitories and increasing sustainability claims of projects under construction.[26] By 2021, on the eve of the FIFA tournament, the press and NGOs returned to reporting on abusive practices in Qatar.[27] Changes and reforms had been ineffective, yet the government soldiered on, largely proceeding as if they had addressed even the harshest of critiques. In truth, it mattered little whether recommendations were adhered to and reforms passed, let alone enforced: Qatar's extractive labor system that pillaged the body of laborers had cultural[28] and historical precedent[29], and the harsh building conditions were touted as the only way to complete the project on time within desired margins of economic success. In this, the Qatari government had not been alone or the first. Similar challenges to human rights were registered during the Summer 2016 Olympic Games in Rio de Janeiro and the 2014 FIFA World Cup in Brazil: both, global sporting events that came under serious public scrutiny for their displacement of impoverished peoples, questionable labor practices, and greenwashing. In the end, all these high-visibility events include building projects that occasion a significant investment in construction and infrastructure projects, commissioned by national and para-governmental entities to rehabilitate reputations and increase financial status. And wherever spectacle at the global scale intersects the circulation of luxury assets, we are likely to identify the perfect circumstances for the trifecta that is 'sports washing', 'architecture washing', and 'greenwashing'.

3.0 LESSONS FROM THE ALL-TOO-COMMON PRACTICE OF 'GREENWASHING'

The use of spectacle, via words or building, to distract is nothing new. 'Greenwashing' is a well-documented and studied practice in which the false advertisement of sustainability performance is used to bolster reputations, be they corporate, political, or institutional. In the corporate space, watchdogs have identified copious evidence of false environmental claims across all industries including aviation, beauty, food, and garment. Possibly, the most egregious, recent example of large-scale greenwashing was that of Cop28, hosted by the United Arab Emirates (UAE) in December 2023. The two-week United Nations (UN) conference charged with combating climate change attracted "85,000 participants, including more than 150 Heads of State and Government" to Dubai.[30] The UN Framework Convention on Climate Change, is responsible for promoting rigorous policy initiatives for reducing global carbon emissions, and yet it chose to locate its signature event in a State whose GDP is led by the fossil fuel industry (oil and gas).[31] The UAE, as an OPEC member and the seventh-largest global producer of oil, was hardly an obvious choice. Moreover, deciding to have Cop28 presided over by Sultan Ahmed Al-Jaber—CEO of the Abu Dhabi National Oil Company (Adnoc), UAE minister of industry and advanced technology, and chairman of Masdar—revealed vast incongruities between UN member aims and those of the host nation.

Greenwashing is so prevalent, that frameworks for helping to recognize and evaluate its frequency have been the subject of rigorous research across various industries and knowledge groups[32] Studies of why corporations, institutions, and governments are frequently cited for incidents of greenwashing indicate that contrary to expectations, where policy initiatives are aimed to encourage higher levels of sustainability and corporate responsibility, the reverse is what results. The more one institutes laws that regulate environmental performance, the higher the chance of greenwashing.[33] Moreover, according to Noémi Nemes et al., the very high rate of the practice is worrisome. In their article "An Integrated Framework to Assess Greenwashing", they recognize that both regulated commercial sectors and unregulated governmental and non-governmental agencies participate in greenwashing as a way of circumventing "making more substantive changes necessary to rapidly reduce negative impacts on the environment."[34] They assert that central to the problem is the absence of an agreed-to "definition of greenwashing or standard of behaviour that would help to detect it."[35] As such, they argue that it is all the more important to identify a framework that would help us measure and evaluate the presence and degree of greenwashing across corporations, governments, and NGOs. To do so, Nemes et al. reviewed more than a hundred academic articles published since 1995 on the subject, conducting a systemic review of "drivers", "varieties" and "impacts", as well as seeking "the meaning, … antecedents, consequences" of, and ways of "reducing" and "detecting" greenwashing.[36] They also examined the internet using associated Google® keyword searches and reviewed government guidelines in the United States, United Kingdom, and European Union for the same. In establishing their greenwashing framework, Nemes et al. identified thirteen different types whose categories they called: Selective disclosure, Empty claims, Irrelevant [claims], Lies, Just not credible [claims], Corporate responsibility inaction, Dubious certifications and labels, Political spin, Co-opted endorsements, No proof, Vagueness, Misleading symbols, and Jargon. In each case, the category identifies how claims that are made can be less than truthful, verifiable, and measurable.

Coordinated reviews of 'greenwashing' practices found in the press, advertising, and business space are made possible by the ready availability of published documents and internet sources. This is not, however, the case, when seeking to study incidents of 'architecture washing'. Recognizing, naming, and measuring when building projects are used for rehabilitating the public image and financial standing of governmental, para-governmental, corporate, or private entities cannot proceed from textual sources alone, as to date the term has little academic currency. Using the Google Ngram viewer, the phrase does not appear at all in print between 1800 and 2019, whereas the term 'greenwashing' was first registered with some frequency in 1989, and when it appeared at its greatest frequency in 2013, it did so at a ratio of .000001000%. (By comparison, the word 'architecture' appeared at its greatest frequency with a ratio of over .000003000% in the year 2000; no doubt, for having been adopted by computer engineering). The situation is the same across scholarly academic searches. Bibliographic resources for 'greenwashing' are substantially more robust than for 'architecture washing'. The latter term does not appear in academic texts allied with the AEC industry. What accounts for this and might we conclude, therefore, that there is no such thing as 'architecture washing"? Not quite, for notwithstanding the lack of a readily available language, definition, or set of metrics with which to identify it, we all recognize when a design, engineering, or construction

project has been co-opted in service to misinformation. Not having the vocabulary to name it does not mean the problem does not exist; it simply means we need alternate means for inferring its theory.

4.0 A FRAMEWORK FOR IDENTIFYING "ARCHITECTURE WASHING": CONDITIONS, MECHANISMS, AND CHARACTERISTICS

What might a framework that helps members of the AEC industry identify, name, and challenge the practice of 'architecture washing' look like? Where might one search for indices of its conditions, mechanisms, and characteristics, if as stated above there are no academic sources on the subject? This paper answers these questions by asserting a productive alignment between architecture washing and forced labor, such that human rights abuses associated with illegal labor practices in the material supply chain of buildings often indicate building projects that are at a higher risk for being used as distractions. Across hundreds of academic, investigative, and news-centered sources collected on the subject, three main research questions arise: What are the material, economic, social, and political conditions that encourage 'architecture washing' in countries and states in which the practice occurs; What are common mechanisms and forms of engagement which render its participants complicit in its goals; What are project characteristics that indicate a higher risk for 'washing' across the delivery process of said project? Each of these questions is addressed below to develop an initial matrix of indicators against which future case studies might be tested.

4.1 Material, economic, social, and political conditions that support 'architecture washing'

This paper asserts the most egregious examples of 'architecture washing' take place where a host of material, economic, social, and political conditions converge; nine of which are herein identified.

1. Systemic and chronic labor shortages that require contractors and sub-contractors to access global recruitment networks for the sourcing of migrant laborers, who at times, are undocumented. The amount of building activity is so high, that the local population is incapable of supplying the required labor force for which recruiters introduce workers from abroad.
2. Evidence of significant income disparities between project sponsors, building users, and building laborers.
3. Building projects have architectural programs that serve the top five percent of global consumers, servicing their luxury lifestyles and capitalized economies.
4. Absence of labor unions or third-party workforce representation on behalf of workers.
5. Lax, or non-existent legal oversight of labor laws, alongside non-enforcement of anti-trafficking laws or supply chain reporting.
6. State-sanctioned lack of transparency in the contractual management of projects that precludes disclosure of how sub-contracts are awarded.
7. Absence of financial oversight by third parties with no mechanism for signaling and reporting possible money laundering or the illegal transfer of funds.
8. Absence of a free press.
9. Disempowered civil society, where non-democratic governments or autocratic rule exist.

4.2 Mechanisms designed to render AEC participants complicit in its goals.

In addition to the high probability of finding the above-mentioned material, economic, social, and political conditions amid the practice of 'architecture washing', diverse yet recognizable business mechanisms are often used to render members of the AEC industry complicit in its aims. Eight such tools and forms of engagement are herein identified. They include:

1. Hiring of 'star architects' by project patrons to impart, by association, cultural significance, and design importance to the project.
2. Use of targeted public relations campaigns, social media posts, and marketing initiatives that include project-sponsored exhibitions, videos, and placement ads.
3. Covert planting of 'news' items in financial and industry press, that are seemingly authored by third parties but sponsored by project patrons offers yet another way of normalizing said project.
4. Invitations to AEC members to participate in travel junkets that help to promote the said project and paid invitations to speak about it do the same.
5. Voluntary applications for sustainability and/or labor certifications and other forms of due diligence accreditation are often used to stave off scrutiny of poor environmental performance or suspected forced labor violations.
6. Co-opting of representatives from sympathetic democratic countries for offering their support to said project, and/or regime when projects are commissioned by non-democratic countries.

4.3 Project characteristics indicative of high risk for 'washing' in its delivery.

4.3.1 Project's contractual and legal definition

1. Projects that are primarily designed as financial vehicles for soliciting global investment by third parties.
2. Expropriating land for the project's site without clear authority.
3. Excessively short or long construction timelines that encumber the successful completion of the project.
4. Lack of transparency amongst AEC member professionals and a bidding and sub-contracting process.

4.3.2 Sourcing of project materials

1. Lack of transparency in the life cycle of materials.
2. Significant amount of the materials used in the project are imported, non-local, fossil fuel derivatives.
3. Building process results in an exorbitant amount of material waste.

4.3.3 Sourcing and management of the project's labor force. When the labor rights of those who are tasked with building the project are at risk of denigration, this too is a sign of concern.

1. A lack of transparency in on-site labor recruitment practices.
2. An out-sized percentage of migrant, non-citizen laborers.
3. The lack of a shared language between laborers and managers (or available translators) for communicating.
4. Excessive travel distances between the building site and worker housing.
5. Inadequate quality in the housing and living conditions.
6. Inadequate worker safety and access to health verifications on and off-site.
7. The inability for laborers to leave the project site at will, and to have access to their citizenship papers.
8. The inability of the same to self-organize or associate with third-party representation.

4.3.4 Building-use and life cycle indicators. There are two key characteristics that when identified during the post-construction life of a building are indicators of possible washing.

1. A low percentage of building occupation and programmatic use upon completion, with large portions of the building remaining empty, not purchased, or unrented. This is often a sign the building was built as a financial vehicle for investment or money-laundering.
2. A poor Life Cycle Assessment (LCA) score, including embodied energy and carbon, given that many of its materials are imported and originate in fossil fuels.

CONCLUSION

This paper has identified, named, and characterized the practice that is 'architecture washing' as experienced in the Architecture, Engineering, and Construction (AEC) industry to demonstrate that when and where it occurs, 'architecture washing' detrimentally impacts the industry, the quality of our built environment, and society at large. Contemporary examples of 'architecture washing' were discussed and a framework was devised for recognizing material, economic, social, and political conditions that encourage its deployment, mechanisms intentionally designed to render AEC participants complicit, and key characteristics in a project's delivery process that exposes said project to high probability for 'architecture washing'.

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Community-based Approaches to Creating Adaptive Solutions for Urban Challenges: Two Case Studies

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ABSTRACT: Addressing diverse social, environmental, cultural, and economic urban challenges requires understanding them as dynamic, complex systems. This paper presents ongoing research within the Baltimore Social-Environmental Collaborative (BSEC), a U.S. Department of Energy Urban Integrated Field Laboratory (IFL). Focused on Baltimore as a midsized U.S. industrial city grappling with equitable solutions to climate change and social injustice, BSEC involves diverse collaborators. It adopts an iterative collaborative cycle relating regional climate trends and other factors with environmental and social priorities to inform community-guided equitable climate solutions. This paper highlights two projects within BSEC's knowledge co-creation process. The first addresses energy poverty, employing spatial statistical techniques and mapping to investigate the spatial distribution of energy burden and provide insight into the social injustice in energy access. The second uses field surveys, computation, and community engagement to develop a data-driven decision-making approach to integrating Blue-Green Infrastructure (BGI). The paper concludes with an overview of engagement methods important to BSEC and informative for other architectural researchers.

KEYWORDS: climate Crises, blue-green infrastructure, community collaboration, equitable pathways, urban energy poverty

INTRODUCTION

Human activities are the dominant cause of global warming trends (EPA 2017). Since the Industrial Revolution, human activities including electricity generation and commercial and residential building construction, agriculture, manufacturing, land use changes, and transportation, have released greenhouse gases (GHGs) into the atmosphere. GHGs, including carbon dioxide as a primary emission, trap heat and cause increases in the earth's surface temperature (EPA 2017). Moreover, land use changes related to urbanization are associated with the urban heat island (UHI) effect, resulting in warmer environments and increased demand for cooling electricity. "Climate change, desertification, and biodiversity loss are heavily interlinked and pose existential challenges to humanity" (United Nations Climate Promise 2022). "Individuals and whole communities – including those most vulnerable and marginalized – have the opportunity to engage in climate action in sustained and more meaningful ways" (Kizhakkethottan 2024). Although climate change is a global issue, equitable pathways for community climate change resilience require local knowledge and acceptance for successful implementation (IPCC 2023). "As the effects of climate change worsen, the heaviest burdens fall on underinvested urban communities and neighborhoods, which already experience more than their share of environmental challenges, including air and water pollution, flooding, a lack of trees, and excess heat" (BSEC 2024). In September 2022, the U.S. Department of Energy (DOE) pledged $66 million for three Urban Integrated Field Laboratories (IFLs) in Baltimore, Chicago, and the Texas Gulf Coast. "*These IFLs will expand the understanding of climate and weather events and their impact on urban systems, including diverse demographic characteristics; differing climate-induced pressures on people and infrastructure; and varied geographical settings*" (DOE 2022). The Baltimore Social-Environmental Collaborative (BSEC) seeks a new paradigm for urban climate research through an iterative collaboration with local communities. BSEC engages collaborators from neighborhood organizations, city government, non-government community development organizations, federal agencies, and several universities. The team is working to establish a people centered, transdisciplinary IFL that begins with community (human health and safety, affordable energy, and others) and city (improved water quality, decarbonization, functioning infrastructure, and addressing heat) priorities, resulting in observation networks that will deliver climate science and design solutions capable of supporting those priorities. The process involves continuously updating observations and modeling to inform community-guided "potential equitable pathways" for climate action. The decision analysis employs an interdisciplinary approach, combining data science and statistics, modeling and simulation, visual analytics, and domain expertise with on-the-ground knowledge and lived experience of local communities to assess and identify resilient paths of action (Hadjimichael 2023).

This paper presents two cases of research conducted within the BSEC project, illustrating the complex interrelations within built environments. The first case uses statistical regression techniques to examine the links between urban energy poverty and determinants, including sociodemographic, architectural, and urban factors (e.g., UHI). We treat census tracts as the unit of analysis and use public data on eight variables as the proxies to capture climate, demography, urban design, architecture quality, and energy poverty in Baltimore. In the second project, we report

ongoing work to identify UHI mitigation solutions using blue-green infrastructure (BGI). We first propose computational methods to investigate the effectiveness of BGI design proposals to reduce Baltimore's UHI. We will then work with communities in Baltimore to identify their needs, wants, and opinions related to the research questions and simulation results in an iterative decision analysis process. The paper concludes with an overview of engagement methods important to BSEC and informative for other architectural researchers.

1.0 ENERGY JUST CITY – EVALUATION OF BALTIMORE'S URBAN ENERGY POVERTY

Access to clean and affordable energy is crucial to the well-being and development of our society (Bouzarovski and Petrova 2015). Energy poverty is defined as insufficient access to modern energy services for domestic needs (Wang et al. 2021; Bouzarovski and Thomson 2018; Awaworyi Churchill, Smyth, and Trinh 2022). In 2020, more than one in four households in the U.S. were highly burdened with energy poverty, and approximately 50% of those households experienced severe energy poverty (Drehobl, Ross, and Ayala 2020a). Additionally, the sections of society that have undergone marginalization and disinvestment experience energy poverty at disproportionate levels compared to the rest of society (Wang et al. 2021; Bednar, Reames, and Keoleian 2017). It is hypothesized that Urban Energy Poverty (UEP) is a form of social injustice affected by socio-spatial inequalities that prevail in cities. This research aimed to gain an advanced understanding of the social, spatial, and economic determinants of UEP in Baltimore City.

Baltimore has undergone years of racial and economic segregation (Grove et al. 2018). The legacy of these practices has been ingrained in the built environment, which continues to perpetuate unjust living conditions for the marginalized population. For example, 19.6% of the population lives under the Federal Poverty Line, almost double the national average (Shrider and Creamer 2022; U.S. Census Bureau 2022). These conditions have created higher UEP in Baltimore City than at the national level. The average energy expenditure for low-income households, i.e., below 100% of the Federal Poverty Line, was reported to be 16% (Ma et al. 2019). In Baltimore, one in every five low-income households experiences a severe energy burden of 19% (Ma et al. 2019), considerably higher than in other eastern U.S. cities. Energy access is critical for meeting basic needs and improving economic opportunities, especially for women, children, and minority groups. However, climate change exacerbates environmental shocks, affecting vulnerable populations and hindering progress toward poverty reduction. In this case study, we identify the local determinants of UEP in Baltimore City and measure their effects to inform possible city-scale mitigative measures.

1.1 Methods

We used spatial statistical methods at the census tract level to identify the links between UEP and its socioeconomic, environmental, and urban determinants. A review of existing studies helps classify the determinants into four categories: socioeconomic, household demographic, architectural and urban, and environmental. We used exploratory regression to narrow the initial list from twenty to eight determinates (Table 1) to reduce complexity and multicollinearity. We then applied generalized linear regression and spatial regression for the selected features to examine the effects of the UEP determinants. The results are visualized and analyzed through mapping.

Table 1: Determinants of UEP and its sources Source: (Authors 2024)

Determinants	Metric	Source	Acronym
Urban Energy Poverty (UEP)	Energy Burden	Low-Income Energy Affordability Data - LEAD Tool 2018	EB
Socioeconomic determinants	Median household income	ACS 2017-2021	L_INC
Household demographic determinants	Percentage of single-parent households	SVI by CDC 2016-2020	SMH
	Health status	PLACES by CDC 2021	HLTH
Urban and architectural determinants	NDBI value	USGS 2021	NDBI
	Architecture quality	311 data 2018-2020	ARCHQ
	Urban Heat Island effect (Proxy)- Average summer surface temperature	NOAA 2021	UHI
	Percentage of households using alternate (alternate to electricity) fuels as primary heating fuel	ACS 2017-2021	FUEL
Environmental determinants	Diesel particulate matter in the air	EJI 2014-2016	AIRQ

1.2 Results

Statistical analyses confirm that UEP is affected by the determinants of interest. The ordinary linear regression model of the selected features shows that median household income, percentage of single-parent households, health status, diesel particulate matter, primary household heating fuel, and architecture quality have a highly significant effect on UEP, whereas the UHI and Normalized Difference Build-up Index had a small effect on UEP (Table 2).

Table 2: Generalized Linear Regression Results. Source: (Authors 2024)

Variable	*Coefficient*	*Standard Error*	*t-Statistic*	*Probability*	*Robust_SE*	*Robust_t*	*Robust_Pr*	*VIF*
Intercept	12.5	2.92	4.3099	0.000030	3.076	4.094596	0.000068	
L_INC	-1.69	0.46	-3.62	0.000389	0.539	-3.146	0.001931	5.99
SMH	0.016	0.006	2.67	0.008136	0.00782	2.160	0.0319	1.77
HLTH	0.083	0.012	6.63	0	0.014168	5.892	0.00000	7.24
UHI	-0.037	0.019	-1.97	0.050093	0.014423	-2.599	0.010082	3.67
NDBI	0.022	0.0112	2.007	0.046	0.010629	2.122	0.035080	4.07
AIRQ	-1.63	0.4917	-3.325	0.001070	0.5431	-3.011	0.002963	3.33
FUEL	0.016	0.00347	4.64	0.000008	0.003394	4.758	0.000050	1.498
ARCHQ	0.014	0.00316	4.61	0.000009	0.004262	3.434	0.000742	1.749

Furthermore, a Multiscale Geographically Weighted Regression (MGWR) Model was created with an R^2 value of 0.8567 and Akaike information criterion (AIC) value of 197.5. The standardized coefficients from MGWR confirm that socio-spatial variables are significant in describing UEP (Table 3). Health status and income levels have the highest influence, respectively. The racially and economically segregated neighborhoods of Baltimore City have always been victims of respiratory diseases due to poor housing conditions. In 1937, the Baltimore health commissioner highlighted the association between poor housing quality and the inner-city tuberculosis rate (Leclair-Paquet 2017). There have been several reports that cite the relationship between socioeconomic conditions and asthma patients in Baltimore City (Ahluwalia et al. 2013; Grant and Wood 2022; Kimes et al. 2004).

Table 3: Summary statistics for coefficients estimates. Source: (Authors 2024)

Variables	*Mean*	*Standard Deviation*	*Minimum*	*Median*	*Maximum*
Intercept	0.0253	0.0374	-0.0404	0.0303	0.0874
L_INC	-0.2469	0.0392	-0.3390	-0.2516	-0.1625
SMH	0.0542	0.0697	-0.0867	0.0346	0.2184
HLTH	0.5501	0.0009	0.5488	0.5502	0.5517
UHI	-0.0940	0.0237	-0.1437	-0.0936	-0.0450
NDBI	0.0836	0.0173	0.0520	0.0827	0.1241
AIRQ	-0.1610	0.0055	-0.1711	-0.1625	-0.1502
FUEL	0.1591	0.0011	0.1572	0.1590	0.1607
ARCHQ	0.1539	0.0583	0.0713	0.1481	0.2457

In line with scholarship, income negatively correlates with UEP (Mashhoodi, Stead, and van Timmeren 2019), while single-parent households (Robinson 2019), health status (Hernández 2016), lack of building quality (Cyrek and Cyrek 2022), and efficiency (Taltavull de La Paz et al. 2022) positively correlates with UEP. Interestingly, UHI aids in lowering UEP due to its influence on building energy consumption (Li et al. 2019). Contrary to the literature, the air pollution proxy, Diesel Particulate Matter (DPM) concentration (Wang, Maruejols, and Yu 2021), has a negative correlation. This could be because DPM is generally high near industrial and urban centers with high vehicular activity and experience higher temperatures.

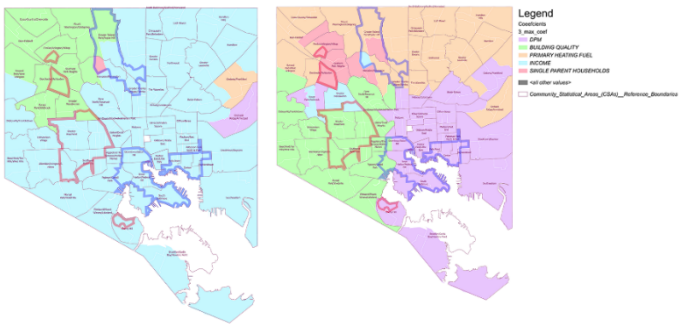


Figure 1: Second (left) and third most influential factor of UEP by census tract. Source: (Authors 2024)

The study confirms that Baltimore City presents a case where building stock quality, income, health, and race are deeply interconnected with energy burden. The western parts of the city (Rosemount and Southwest Baltimore) with the highest energy burden are highly affected by health, status income, and architecture quality (Figure 1). These areas have been historically affected by major blight conditions. Weatherization assistance for low-income populations could be extremely helpful. Spatial injustice without intervention can perpetuate a vicious cycle of energy injustice, widening the gap in energy inequality. Equitable pathways for climate action, such as retrofitting of inefficient housing stock, upgrading to clean energy systems, and addressing UHI can simultaneously address energy, greenhouse gas (GHG) emissions, and the local desire for improved streetscapes and buildings.

2.0 BLUE-GREEN INFRASTRUCTURE TO ADDRESS UHI

Urban development substantially alters natural surfaces, resulting in a range of environmental effects (Girardet 2020). Of them, the UHI effect is an alarming phenomenon where the ambient temperature in cities becomes higher than in the surrounding rural areas (Erell, Pearlmutter, and Williamson 2011). Temperatures in several large U.S. cities, including Baltimore, have increased by about 0.5-3.08 ℃ over the last 100 years (Akbari, Pomerantz, and Taha 2001). Relatedly, extreme heat and flooding are among Baltimore's most critical environmental challenges (Baltimore Office of Sustainability 2015). As indicated above, the median energy burden of low-income households in Baltimore is four times higher than that of non-low-income households (Drehobl, Ross, and Ayala 2020b). Therefore, in the interest of equitable solutions, these neighborhoods are a focus for climate action intervention.



Figure 2: Urban context of Baltimore with limited natural elements. Source: (Author 2023)

The European Commission defines Blue-Green Infrastructure (BGI) as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Environment Agency 2013). The term BGI emerged in the context of planning efforts in Sao Paolo, Brazil, specifically aimed at creating a network of "green and blue" infrastructures in response to flood risks (Frischenbruder and Pellegrino 2006). Literature from 1989 to 2015 indicates a shift from earlier concepts like Green Infrastructure (GI) to BGI, reflecting an integrated approach that aims at various ecosystems and associated services (Silva and Wheeler 2017). This shift moves from a simplistic "land use view" toward more adaptable ecosystem service-based solutions (Haase 2015; Haase, Haase, and Rink 2014). BGI incorporates not only green (vegetation) and blue (water) elements and processes but also interventions like permeable pavements, bioswales, retention basins, and constructed wetlands as an integrated whole (Ghofrani, Sposito, and Faggian 2016; Scott et al. 2016). These interventions can create a cooler outdoor microclimate in the city, decreasing the need for indoor cooling and, thus, reducing residents' energy burden (Drehobl, Ross, and Ayala 2020b).

It is hypothesized that BGI interventions can effectively mitigate the UHI effect (Gonzalez-Meler et al. 2013; Kuller et al. 2018; USEPA 2015). However, little research has investigated the impact of BGI on the UHI effect in Baltimore. Moreover, the lack of data-driven decision-making approaches that help create a comfortable urban microclimate within communities, especially where residents are impacted by UEP, motivated us to develop one for Baltimore by integrating BGI. From this approach, several BGI design and implementation directives can be generated to mitigate climate risks and reduce the energy burden on Baltimore's residents.

2.1 Project goals

The project goal is to establish a comprehensive framework that facilitates BGI implementation as an equitable climate solution in Baltimore neighborhoods. This framework aims to methodically assess and suggest BGI initiatives to ensure effective implementation, addressing environmental concerns while garnering community support and endorsement. This project is guided by two key objectives: 1) investigating the potential of BGI interventions to improve outdoor environmental conditions in terms of air temperature, relative humidity, and air velocity at the neighborhood scale, and 2) exploring the influences of BGI interventions on outdoor thermal comfort levels, with a focus on community acceptance of widespread adoption. These objectives align with the broader goal of establishing a resilient and sustainable urban environment in Baltimore through strategic BGI implementation. A fundamental goal of the study is to devise decision-making approaches that combine quantitative and qualitative data obtained from computational modeling and community engagement.

Community engagement is a fundamental principle that fosters creating sustainable, inclusive, and livable urban spaces. Inclusivity is a core principle of community engagement. By involving a diverse range of community members, including marginalized groups, in the design process, urban planners and designers can work towards creating equitable spaces that cater to residents' needs (Gehl 2011). Communities possess invaluable local knowledge and a unique perspective on the urban environment (Moughtin 2003). This knowledge is indispensable in crafting urban design solutions that resonate with the people most impacted. When people are involved in shaping their urban environment, they develop a sense of pride and responsibility (Talen 2000).

2.2 Methodology

This research commenced in January 2023 and spans five years. The methodology involves an iterative approach that builds from a literature review and involves computational modeling of UHI (Tariq, Poerschke, and Iulo 2023) and resident input. Quantitative data from simulation studies and qualitative inputs from the community workshop will be combined using decision science methodologies. The literature review identifies the causes of UHI, scopes of BGI, and critical factors to human outdoor thermal comfort. Vulnerable areas in Baltimore are then selected based

on the literature review and field surveys. Community Workshop 01 involves presenting potential BGIs to stimulate discussions and understand community preferences and expectations. Subsequently, a simulation study using ENVI-met software predicts environmental impacts, comparing existing conditions with modified models incorporating the preferred BGIs. The impact of BGIs will be analyzed based on the impact on outdoor air temperature, relative humidity, air velocity, mean radiant temperature, and outdoor thermal comfort using the Universal Thermal Climate Index (UTCI). During Community Workshop 02, simulation outcomes will be disseminated, reassessing community acceptance. BGI design guidelines will be developed based on effective and socially acceptable BGI interventions, integrating community perspectives and simulation outcomes, utilizing knowledge co-production for inclusive decision-making. An "XLRM" framework, which considers external factors, policy levers, relationships, and performance metrics (Kwakkel 2017), will be utilized to discern the most effective and acceptable BGI intervention for Baltimore. The research intention is to develop a comprehensive BGI intervention design and implementation framework that is applicable in Baltimore and adaptable to similar contexts.

2.3 Study significance

The symbiotic relationship between participation tools and urban interventions is pivotal in urban design practices. Participation tools serve as conduits for gathering data from urban interventions, facilitating the synthesis of the collective knowledge base. Simultaneously, urban interventions can offer context-specific platforms that yield novel perspectives and avenues for study. Despite their complementary nature, the comprehensive conceptualization of urban interventions and participation tools within urban design processes remains a largely disregarded interdisciplinary research domain (Ataman and Tuncer 2022). This project unveils new vistas and themes, each contributing to an enriched understanding of urban design dynamics by generating interdisciplinary and integrated state-of-the-art BGI intervention guidelines for urban planners, policymakers, and community decision-makers.

3.0 DISCUSSION – NEED AND METHODS FOR COMMUNITY ENGAGEMENT TOWARD EQUITABLE PATHWAYS

More than 3.3 billion individuals now reside in regions highly susceptible to the effects of climate change (IPCC 2023). Without adequate support for climate adaptation, they confront an increasing array of hazards. Recent agreements on climate adaptation funding indicate a growing commitment to assisting frontline communities that are socially and institutionally disadvantaged, belong to low-resource groups, and face a disproportionate burden from climate change impacts (Araos et al. 2021; Sanders 2021). We argue that there is a growing need for scholars and practitioners to bring forth the active involvement of local communities for sustainable and inclusive solutions in urban development. Fostering community engagement for climate change adaptation has become a cornerstone for not only acknowledging diverse perspectives but also co-creating interventions that are contextually relevant and socially just (Harrison et al. 2022; Moser 2014; Samaddar et al. 2021).

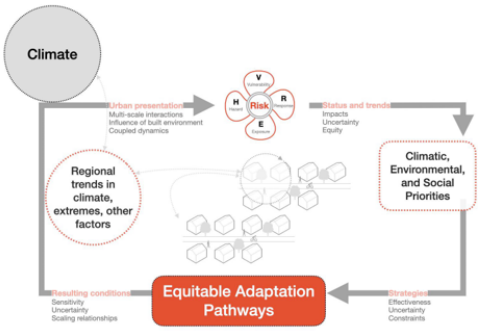


Figure 3: BSEC's focus on Equitable Adaptation Pathways; Source: (The Baltimore Social-Environmental Collaborative IFL Proposal, Benjamin Zaitchik)

BSEC's focus on Equitable Adaptation Pathways (Figure 3) reflects a new urban climate research paradigm integrating iterative collaboration with local communities. Through investigating building to metropolitan-scale climate change impacts, climate risks, priorities, and constraints are translated into equitable adaptation pathways to be reviewed and fine-tuned in partnership with community stakeholders. Such an approach helps ensure that future urban development initiatives align with the needs and aspirations of the people they serve, fostering a sense of ownership and resilience.

Achieving effective community engagement involves tailoring strategies to specific community needs and contexts (Samaddar et al. 2021). This includes fostering inclusivity and implementing participatory methods, such as workshops, town hall meetings, and focus groups, to facilitate direct interactions between community members and policymakers. Technology, such as social media and online platforms, enhances outreach and ensures diverse perspectives. Equipping community members with the necessary knowledge and skills for active participation in decision-making is a key aspect of capacity-building that helps sustain engagement. Storytelling and visual communication methods are also beneficial in overcoming language and literacy barriers, making information more accessible to a broader audience (Moser 2014). Addressing urban challenges requires interdisciplinary collaboration among stakeholders, including government agencies, NGOs, and local businesses. Adapted to local contexts, these methods are crucial for genuine community engagement and equitable urban development (Adib,

Wu, and Flohr 2023; Samaddar et al. 2021). Moreover, addressing sustainability challenges like climate change requires new knowledge to tackle their social and ecological complexities and scale. Knowledge co-production fosters actionable and equitable science, bridging academic disciplines and social spheres amidst rapid social and environmental change (Zurba et al. 2022). Equity, commonly understood as the fair and just treatment of individuals, is integral to knowledge co-production. Achieving equity involves intentional efforts throughout project processes, eliminating obstacles to participation. Non-indigenous researchers should practice empathy, strive to understand local perspectives, and identify participation obstacles for indigenous members. Proactive measures are crucial, underscoring the importance of collaborative planning with local partners to recognize and address barriers early (Herman-Mercer et al. 2023).

Community involvement in climate solutions is believed to enhance decision-making quality, trust, democracy, and community satisfaction, fostering ownership over green spaces and longevity of projects. However, these benefits can be compromised by unequal representation and obstacles to sustained participation (O'Donnell et al. 2021), especially when engagement is under-resourced and prioritizes dominant voices over marginalized groups. This issue is exacerbated when local and national governance structures do not support true power-sharing between governmental and non-governmental stakeholders. Effective decision-making requires engagement strategies that genuinely consider, reflect, and respond to community needs and capabilities. This process involves various methods, from informative public relations campaigns and lectures to more interactive approaches such as canvassing, public meetings, surveys, and comments. Additionally, consultative methods like interviews, focus groups, facilitated group discussions, expert workshops, and co-creative methods like learning alliances and living labs are used. Surveys and questionnaires are also commonly utilized, alongside the growing use of social media and GIS-based methods. However, digital approaches can also reinforce exclusion. The choice of engagement methods is influenced by factors including goals and motivations for engagement, resource availability, and timing considerations. Understanding appropriate methods and resources for equitable inclusion is crucial in minimizing negative impacts, requiring exploration of their efficacy across contexts and community groups (Rahtz et al. 2023).

4.0 CONCLUSION

Concerns about Urban Energy Poverty and Urban Heat Island extend beyond rising surface temperatures and into the realms of environmental justice, equity, and public health. These concerns necessitate the development of effective mitigation measures, many of which come in the form of green infrastructure projects and improved housing. We introduced two ongoing architecture and landscape architecture case studies within the BSEC IFL to highlight the need to integrate community-engaged science for developing equitable climate solutions. These projects illustrate the breadth and depth of BSEC's endeavors and exemplify innovative strategies to generate meaningful change. By championing climate and social solutions aligned with community values, BSEC's model of community-oriented interdisciplinary urban science holds immense promise and lays the groundwork for transformative urban interventions. Ultimately, achieving equitable adaptation pathways requires proactive engagement with both professionals and community members to foster collaboration, co-create solutions, and ensure that adaptation strategies are responsive to the diverse needs and perspectives of urban residents. By embracing participatory approaches and prioritizing community input, planners and designers can create more resilient, inclusive, and sustainable cities better equipped to address the challenges of climate change and social equity.

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ADAPT: A Collaborative Approach to Accessible Affordable Housing

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ABSTRACT: This paper describes the outcomes of an interdisciplinary research collaboration focused on a call issued by the United States Department of Housing and Urban Development (HUD) to address a need for designs for accessible affordable housing and plans for modifications necessary to make homes readily adaptable to meet the needs of individuals and families seeking to age-in-place (AIP). Specifically, the research team was directed to considered housing types with four or fewer units, commonly described as 'missing middle' or 'middle density' housing types, which fall outside of the purview of United States Fair Housing Agency (FHA) and the Americans with Disabilities Act (ADA) guidelines.

Two working groups established foundational research for the team and advisory council's review before moving into design work. One working group's literature review revealed numerous scattered high-quality resources addressing a range of topics from spatial considerations to financial resources and funding programs for aging-in-place renovations and new construction. The second working group conducted a series of focus groups with individuals with mobility and visual disabilities seeking to age-in-place.

After presenting these findings to HUD, the project team shifted approach from developing renovation design plans and singular housing prototype designs to the development of a web-app that consolidated AIP best practices and resources and to a consideration of aging-in-place more broadly than the specific design of non-detached single-family homes, semi-detached townhomes, and structures with four or fewer residential units. The team explored housing prototype design solutions that reinvested in neighborhoods with substantial vacancy by identifying land banked properties and zoning changes that would allow infill development of a range of middle density housing types. The design studies propose infill development of middle density housing types in neighborhoods with land banked properties and a return to prior land use scenarios through zoning modification.

KEYWORDS: affordable housing, accessibility, aging in place, interdisciplinary research

INTRODUCTION

Affordable, accessible housing is in great need in the United States. The elder population is growing as "Baby Boomers" retire, as well as individuals live longer. Overwhelmingly, Americans would like to remain in their homes as they age, referred to as "Aging in Place", or AIP. Homes must be accessible, safe, and affordable for individuals to successfully age in place, yet many homes were not originally design to allow for this possibility. These homes would need to be retrofitted with the appropriate features to allow for accessible, independent living.

The demographics in the United States are continually, but predictably, changing. The US Census Bureau estimated that in 2019 nearly one out of every three Americans (29.4 percent) was over the age of 55 (Bureau, US Census. n.d.). This segment of the population has steadily increased since 2010, when approximately 25 percent of the population was over the age of 55.

As we grow older, though, our physical needs may change. We may no longer be as mobile as we once were, or our vision may not be quite what it used to be. If our physical needs change, the homes we live in may no longer suit those needs. For example, the American Association of Retired Persons (AARP) found that approximately one in three adults that own their own home (of any age group) would need to complete "major modifications" to accommodate aging needs (Shinkle 2011). This is due to the fact that historically, single-family attached and detached homes have not been built with accessibility in mind, meaning they were not built in ways that would allow a person with disability to safely and independently live there.

The American Association of Retired Persons (AARP) found in their 2018 Home and Community Preferences Survey that nearly 80 percent of adults age 50 and older want to remain in their communities and homes as they age (Binette 2021). The concept of adults staying in their homes as they get older is commonly referred to as "Aging in Place" which can be defined as he capacity to reside in one's home and community securely, autonomously, and comfortably, irrespective of age, income, or ability level.

1.0 FRAMING THE QUESTION

In early 2016, the United States of America Department of Housing and Urban Development (HUD) issued a notice of funding related to "Accessible Housing and Technology Research and Demonstration[1]" with the following call:

> The objective of the research funding is to support studies on innovations in the design and construction of affordable, accessible, and aesthetically pleasing housing with a particular focus on technological adaptations that could be made to existing housing designs for persons with disabilities, and to identify, evaluate, and test the home modifications and technology innovations necessary to make existing housing accessible. Additionally, the studies were to focus on non-detached single-family homes, semi-detached townhomes, and structures with four or fewer residential units. The researchers were to be guided by interdisciplinary advisory teams representing a variety of interests in the field of accessible housing. (FR-6000-N-29, United States Department of Housing and Urban Development)

In response to the agency's call for research the authors developed a team of faculty, graduate and undergraduate student researchers from multiple schools within the university. While the core research team was comprised of faculty from Architecture, Construction Management, Industrial Design, and Auburn University's Center for Disability Research and Policy Studies, an advisory panel of individuals representing a variety of perspectives in the area of accessible housing and design was developed to help guide the research. The research team answered the call and explored (1) what aging-in-place (AIP) best practices should be implemented in the renovation of existing homes, (2) how AIP best practices can be disseminated to homeowners, designers, and contractors, and (3) the development of prototype middle density housing designs that incorporate AIP best practices.

1.1 Identifying resources

Two working groups were formed to understand the call and identify already available resources. A working group led by the Director of the Center for Disability Research and Policy Studies conducted a policy review and hosted a series of focus groups. The feedback from the focus groups were the most instructive for the team as much of the policy was known or not applicable. The focus group leader identified two filters to apply to the discussion of aging-in-place, mobility and vision, noting that visual acuity and ambulatory steadiness decline with age and significantly impact an individual's ability to perform instrumental activities of daily living (IADL).

Responses from the focus group confirmed the impact of declines in visual acuity and ambulatory steadiness on an individual's ability to age in their own home without making minor and more substantial changes to their residence. In many cases these changes are simple and inexpensive, however in some situations (rental, restrictive covenants, etc.) modifications to a residence face significant challenges. Most of the participants in the focus groups rented their home. As they noted, changes to the building (doorways, hallways), fixtures, appliances, hardware were elements that could not be altered without the agreement and consent of the building owner. For those who owned their own homes, many had developed their own adaptations of their own spaces and appliances.

The focus group leader noted that participant responses varied based upon both type and severity of impairment, however there was significant overlap in common areas of the home. Focus group participants were asked to provide feedback about specific spaces, items and concerns faced in their homes. Both groups identified specific challenges with respect to their particular physical ability, however the magnitude of responses varied as can be seen in the graph in figure 1.



Figure 1: Physical ability challenge overlay. blue:visual acuity, pink: mobility. Source: (Authors 2022)

The responses from the participants in the focus groups provided the second working group a valuable lens through which to survey of available resources for those seeking to adapt a home to anticipate age-related declines in mobility and visual acuity encountered while aging in place. This working group, led by the principal investigators (Pi) and graduate research assistants from the Auburn University's College of Architecture, Design and Construction, sought to determine what aging in place resources, including federal guidelines[1], academic journals[2], web-based resources, and published guidelines were available for reference to designers and contractors when embarking on an aging in place-related project. A literature review was undertaken to answer this question, which included broad Internet searches, as well as searches through academic databases, libraries, and bookstores.

It quickly became clear that there is an abundance of easily accessible publications (meaning available for free download on the internet, or a widely published book) on aging in place. The publications come from a variety of

sources, including the National Association of Homebuilders, the New York City Department on Aging, the American Society of Interior Designers, and Harvard Medical School, to name a few. Some publications addressed just the built environment, meaning how homes can be adapted to meet aging in place needs. Other publications took a more holistic view, describing general topics such as physical, mental, and financial health, as well as how to become part of a community.

In total, the ten publications identified by the research team provided 184 best practices, or recommendations, of certain physical items or configurations of items to be incorporated into a home to allow the homeowner to successfully and safely age in place. To visualize and evaluate the 184 recommendations identified in the literature review, the research team created a series of drawings depicting generic space types commonly found in residential buildings and mapped the recommendations to these spaces when applicable. Where not spatial, the recommendations were included as annotations. This process allowed the team to identify patterns of recurrence as well as to further distinguish between recommendations focused on mobility or visibility. The drawings and reviews with the research team aided in the process of distilling the initial list down to a final list of 50 recommendations.

The research team then surveyed industry professionals to determine which of the 50 aging in place best practices were currently being implemented by contractors and designers when engaged in complete renovation or new construction projects. It was found that the most prevalent reason that AIP best practices are not integrated into renovation and new construction projects was that the homeowners did not request them.

2.0 DESIGN PROPOSALS

Following the exploratory phase of the research, the team met with the advisory group and HUD to discuss the next phase of research. In advance of this meeting the teams review of the research led to two parallel trajectories.

The first was to develop an interactive web-app designed to educate and inform the public on AIP best practice implementation, consolidate scattered information and connect the public to professionals and locally available financial resources for AIP and accessibility home modifications.

As the team reviewed design guidelines and developed plans of existing attached and semi-attached housing it became clear that single solutions would only resolve issues for a small minority of residences. Rather than prototypical solutions to uncommon conditions the team sought to address the fundamental obstacles in homes and identify strategies and resources for adapting a home to meet a specific user's needs.

The team decided that a web-app would aggregate and make available to a wide audience the best information, resources, and contacts for adapting a home for aging in place. The overarching goal is to enhance the capacity for independent living among people with disabilities and those seeking to age in place through new and existing home design solutions that are affordable, sustainable, and capable of adaptation to meet individual needs. The app, called ADAPT, focuses primarily on assisting people to adapt their homes to accommodate disabilities.

The second emerged from the observation that the notion of aging in *place* was not necessarily tied to the residence as was revealed in the literature review and the responses of many in the focus groups and advisory panel. The team began to consider this in the approach to the design of housing prototypes and made a suggestion to evaluate a specific location to ground the design process in a place.

A significant finding from this exploration was that current land use regulations (zoning restrictions) in many municipalities limited the development of middle density housing or only allowed it in areas that were not close to the types of necessary services or amenities desirable for individuals with physical disabilities seeking or seeking to age in place.

With feedback and approval from HUD the team began the development of the web-app and began exploring designs for middle density housing prototypes that would stretch zoning and suggest alternatives to current models based on input and feedback from the research advisory panel, focus group, as well as non-profit affordable housing developers.

2.1 Adapt web app

The word "adapt" is defined as "to make fit (as for new use) often by modification." ("Definition of ADAPT." n.d.) research team decided to title the web-app "ADAPT" as we felt this sentiment was exactly our charge; to educate the populace on how our practices as homeowners, designers, contractors, and educators should be modified to address the ever-growing need for AIP-friendly housing, as well as how the structures themselves should be altered.

The ADAPT app (figure 2.) was conceived with a diverse potential audience of app users each seeking overlapping yet also different information, navigation through diverse yet interrelated information sets became a driving factor in the design of the app. The target audience of the app includes the elderly, people with different types of disability, the adult children of the elderly, family members of people with disability and building professionals such as builders, interior designers, architects, and building contractors. This variety of potential app users influenced, navigation, access routes, and information retrieval and distribution needs and led the app design to be organized around three main categories of information: recommendations, tips and resources.

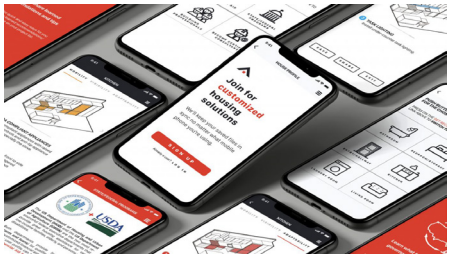


Figure 2: Adapt web-app. Source (Authors 2022)

Recommendations provides spatial recommendations organized around three categories: mobility, visibility, and adaptability. These room recommendations are accompanied by an illustration indicating the areas in the room impacted. As each recommendation represents an adaptation to one's home aimed at improving one's ability to use a space by focusing on mobility and visibility in each room, the final section (adaptability) describes a scope of work necessary to implement desired changes to the room.

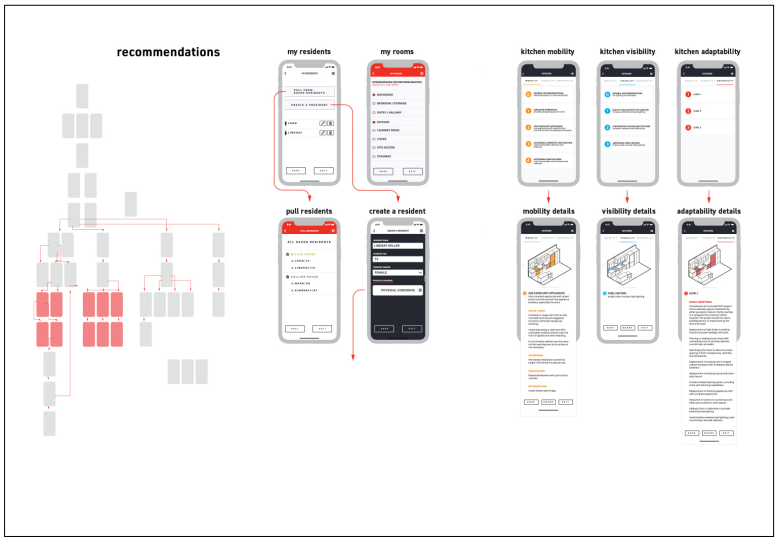


Figure 3: Adapt web-app Recommendations navigation. Source (Authors 2022)

Tips provides information about seeking financial aid, or state and federal programs that support aging in place housing renovation or construction. The tips are saved to a user profile (if created) and are searchable within the app as a checklist.



Figure 4: Adapt web-app Tips and Resources navigation. Source (Authors 2022)

Resources provides links to professionals with expertise in aging in place design and renovation, the app links to a national directory of certified aging in place professionals (CAPS).

As part of the development of the ADAPT web app, the research team developed a series of space type studies based upon AIP best practices. Through several iterations the team revised the recommendation drawings and applied them to designs for new construction of middle density (two, three, and four unit single-family attached and detached homes) that incorporate aging in place best practices. The prototype designs were developed with a team of students working with the researchers over several months and were reviewed and revised with input from the entire team. As the designs developed from the interior the team also began to evaluate potential infill opportunities

that would expand the ability to age in one's community, which led to the decision to use a neighborhood in Birmingham Alabama as a site for the home designs.

2.2 Adapt design prototypes

The research team entered this phase of work with the following question. If the place in which one lives, includes the home as well as the neighborhood and community in which one is a member, how might our homes and our physical communities be adapted to provide a broader range of accessible, affordable places in which one can age?

Working iteratively prototypes were developed that would infill into existing neighborhoods with existing physical and social infrastructures. These middle density types (ADUs, du-, tri-, quad- plexes, and townhomes)[3] share a similar scale with single family housing and have traditionally been found in most pre-1950's U.S. urban neighborhoods. These types allow for smaller and more varied housing options with increased density and access to shared amenities.

The team decided to study an urban neighborhood in Birmingham, Alabama. East Lake was selected due work by local nonprofits spurring redevelopment efforts in the neighborhood and surrounding neighborhood. Both Habitat for Humanity and the Woodlawn Foundation have increased affordable housing options in the area with attention given to aging in place concerns. Additionally, East Lake is located within an opportunity zone[4] and has over 4,000 parcels held by the Birmingham Land Bank Authority, which currently holds 8,000 properties[5].

Birmingham is one among many U.S. cites that has a Land Bank Authority. Land banks are governmental entities that obtain vacant, abandoned, tax-delinquent and foreclosed properties with the goal of returning them through sale into productive use, including housing developments or public amenities. The idea of land banks came about during the 1970's as a way for municipalities to collect (i.e., bank) inner-city properties that were abandoned or deemed undesirable as a function of urban sprawl, for future use. This focus has shifted in recent years to the accumulation of properties that have been deserted by their owners due to a variety of reasons, such as poor functional conditions of the structures on the properties, property value depreciation due to neighborhood blight, or severe tax delinquency. Land bank authorities acquire the properties and assist with clearing title and tax delinquency for future public or private use. Over half of all states have at least one land bank authority.

As the team developed the prototype designs it became clear that smaller housing options (specifically ADUs) would provide a flexible and reconfigurable solution for accessible, affordable housing. Under current zoning regulations, these types of dwellings would not be permitted by right. While it is not impossible to petition for permission to construct an ADU or -Plex, the additional steps required to do so places these kinds of projects out of the reach of many, as the additional steps add cost and time to the process of permitting and constructing an addition or developing an affordable and accessible project. The team explored a small adaptation of the zoning, by simply up zoning the current neighborhood to allow slightly higher density development. Of note, the neighborhood contains many examples of middle density development that existed before current zoning was established.

As the team began to study land bank parcel locations other members of the team assessed the East Lake neighborhood. The neighborhood has existing parks, sidewalks, schools, restaurants, churches, and small retail establishments that serve the community. The community consists of 3,336 individuals. Of that group 474 (14%) are in the age category of 65+. 213 (45%) of this group own their homes. Of the 474, 152 (32%) are disabled. The U.S. Census Bureau defines a disability as a physical or mental impairment that affects one or more major life activities, such as walking, bathing, dressing, eating, preparing meals, leaving the home, or doing housework.

Eastlake's location within the city and larger transportation network provides for good connectivity with the surrounding neighborhoods, central city airport and large recreational areas (Ruffner Mountain and East Lake Park and Wahoma Park). Neighborhood amenities along with municipal bus route walk radii were mapped to identify potential prototype test sites. These sites provided opportunities to consider infill development patterns that took advantage of specific conditions of their concentrations of landbank sites and relative proximity to transit and local amenities.

Four sites were identified, and a series of studies were undertaken to understand the potential impact of the proposed zoning shift on the urban fabric and connection to identified amenities and transportation networks. Additionally, the team quantified the number of potential middle density unit types that could be built on landbank, and tax delinquent properties compared to a single-family residence infill. These types of changes are already taking place with several cities leading this effort. Austin's Alley Flat initiative restructured zoning and streamlined permitting for alley flats (ADUs). Seattle, Portland, and Los Angeles have modified their zoning to increase housing options in the face of a housing crisis and aging population. In many ways the designs of the individual homes are less important, than the social landscapes that are created. Pocket courtyards, repaired sidewalks, shared porches, micro retail, or satellite medical centers that provide opportunities for the young and the young old to engage with their community.

As an example, one of the sites studied (figure 6) is comprised of 75 parcels that cover approximately 15-acres, with individual parcels being approximately 0.2 acres in size. The tax value of the total site is approximately $88,000 per acre, and the current potential density is 4.9 residences per acre. 24 of the 75 parcels, or 32%, are land-only, and have no habitable structures on them. The remaining 51 parcels have vacant homes that were originally built around 1930, and each have a current tax value of approximately $33,000. The average home size is 1,400 square

feet, has 2-3 bedrooms, and 1 bathroom. 28 of the 75 parcels, or 37%, are land bank-owned, or land bank-eligible due to severe tax delinquency.

The team developed a proposal for the site that suggested nine structures totaling over 12,08 square meters (13,000 square feet) would be removed. Approximately 80% of the existing building stock would remain. 28 new main structures totaling nearly 8,175 square meters (88,000 square feet) would be built, plus 58 ADUs totaling over 4366 square meters (47,000 square feet). This would equate to 8.5 housing units per acre of land, and 3.8 ADUs per acre of land. 93 housing units would be built, which would be a mix of unit types. The average home would have 2 bedrooms, and one bathroom. Average home size would decrease to approximately 116 square meters (1,250 square feet), or 11%. The proposed design would increase the average tax value of the land to approximately $94,000 per acre, or a 7% increase. The average tax value of the buildings (per parcel) would rise to approximately $131,000, or a 296% increase. (figure 7)



Figure 5: Site study area. blue: proposed middle density housing types. Source (Authors 2021)

The new residential buildings in the plan are bordered by a commercial corridor. Public transit stops are located within the study neighborhood. The prototype site design focuses on the opportunity to engage the transit and introduce micro retail into the neighborhood and provide an additional amenity to the neighborhood. (figure 8)



Figure 6: Site study area. blue: proposed middle density housing types. Source (Authors 2021)

CONCLUSIONS

Had the research team been centered in one disciplinary domain the questions brought to bear on the research would have been narrowly focused and would have been slow to access outside domains of knowledge. Methods

of gathering and testing information and ideas were discussed and considered through multiple points of view. And most significantly the broad agreement across the multidisciplinary team to shift direction bolstered confidence in the direction of the research.

Major findings the team identified ranged from policy and guideline limitations. FHA guidelines were designed for multi-family structures with greater than four housing units. ADA guidelines were designed for public, commercial spaces. Hence, these guidelines do not sufficiently address AIP best practices, especially those applicable to “missing middle” and single-family residences, as they were not designed to.

Academic journals revolving around research into aging exist, are robust and growing rapidly. Unfortunately, articles in these types of publications are mainly written by academics, for academics. Furthermore, these journals are not always available for public consumption.

There are a substantial number of easily accessible books and web-based resources on AIP which are intended for public use. Many best practices are provided in these numerous yet scattered resources. The research team found 50 AIP best practices through analysis of these publications, which are applicable to renovation and new construction residences.

Paralleling demographic trends, an increasing aging population, later ‘family formation and expansion, as well as an increase in multi-generational living provide an impetus to revisit housing types. The prototype designs were developed using the AIP best practices contained in the ADAPT app and suggest that small adaptations to zoning allow for slightly increased density opening districts to a wider variety of housing options for residents. Utilization of land banked properties allows for a finer great redevelopment that infills within the existing context, reinforcing existing physical infrastructure and enhancing the social infrastructure.

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ENDNOTES

1. The United States congress enacted the Americans with Disabilities Act of 1990 (United States 1990), with the intention to “provide a clear and comprehensive national mandate for the elimination of discrimination against individuals with disabilities.” ADA design standards were developed, and first published in 1991, with updates to the standards published in 1994, and in 2010. The standards were made applicable to “places of public accommodation and commercial facilities by individuals with disabilities.” The Fair Housing Act was enacted in 1968, and is meant to “protect people from discrimination when they are renting or buying a home, getting a mortgage, seeking housing assistance, or engaging in other housing-related activities.” The Fair Housing Act prohibits discrimination based on an individual’s race, color, national origin, religion, sex, familial status, and/or disability. Regarding disabilities,

The Fair Housing Act Design Manual published in 1996 (and updated in 1998) (U.S. Department of Housing and Urban Development 1998) states that: “The design and construction requirements of the Fair Housing Act apply to all new multifamily housing consisting of four or more dwelling units. Such buildings must meet specific design requirements so public and common use spaces and facilities are accessible to people with disabilities. In addition, the interior of dwelling units covered by the Fair Housing Act must be designed so they meet certain accessibility requirements.”

2. The academic aging in place literature generally falls into six categories: (1) technology to assist aging in place, (2) building or naturally occurring communities to support aging in place, (3) older individual’s perceptions of aging in place, (4) governmental policies, (5) the efficacy of home care services, and (6) rural aging in place. The research into these topics is abundant, and ever increasing, especially technologies to assist AIP. One interesting highlight of the academic literature is a finding from Wiles et al. (2012), that the phrase “aging in place” is extremely popular among policy makers and service providers, but not familiar to most older people.

It is worth noting that academic publications are oftentimes written and published in a manner that is only useful to other academics. The general population may not even have access to these publications, as many academic journals are only accessed on a subscription basis, with university libraries being the top subscriber. (Wiles 2012).

3.ADU+, Accessory Dwelling Units (ADUs) are small independent dwellings located on the same property as a detached residence. ADUs can be a detached structure, attached to the principal structure, or within the existing structure. The size of an ADU is dependent upon local ordinances and these are changing rapidly as many municipalities see the value of this form of development. For homeowners they offer the opportunity for passive income in retirement, for extended families to live near one another while maintaining privacy, and as smaller structures are an affordable option as site infrastructure is shared with the principal residence.

adu cluster, the adu+ prototypes were designed to accommodate scenarios around changing family structures and population demographics, and to be utilized in cluster or cottage developments. In these types of developments, a cluster of typically 4-12 units are arranged around a common exterior space, (p. 104) and a homeowner's association (HOA) is formed for maintenance of the common. The HOA if written carefully could be a useful entity in maintaining the development and lessening the need for elderly residents to be responsible for exterior maintenance. At the same time this type of development is organized around common exterior spaces which provide an opportunity for residents to gather and socialize.

plex+, Plexes are small scale multi-unit housing on a single property. The individual units are often organized as side by side, front to back, or stacked units. Rather than stacked flats, the prototypes are based on a series of small units that can be configured front to back in order to maximize accessible ground floor units. The units aggregate to create front-to-back and stacked duplexes, as well as triplexes and fourplexes following the same pattern. The triplex was designed with the ability to create a micro retail space on the ground floor. These spaces (600-800 sf) could be outreach healthcare facilities, coffeehouse, or small neighborhood shops.

townhouse+, A townhouse is an attached single-family residence usually consisting of 4 to 16 multi-story units sharing one or two fire walls with an adjacent dwelling. Each unit is located on its own individual parcel, usually with a front and back entry and parking on site. In some cases, a homeowner's association (HOA) is formed if there are shared amenities. Typically, a townhouse is configured as a linear cluster lining the street (left), however there is no requirement to do so. The prototype townhouses utilize the ADU+ plan as a basic unit reconfigured based upon site opportunities to create more defined common areas. This effectively creates the need for an HOA, which alleviates the need for individuals to maintain the structure and maintains a shared common area as seen in the 'j' and 'u' configurations at left. As with the ADU+ in the cluster or cottage housing configurations the HOA could be leveraged to convert a ground floor unit into an amenity space shared by the building residents.

4. Opportunity Zones: Created in 2017 under the Tax Cuts and Jobs Act (United States 2017), an opportunity zones are defined as "an economic development tool that allows people to invest in distressed areas in the United States." These zones are defined by census tracts boundaries and are intended to "spur economic growth and job creation in low-income communities while providing tax benefits to investors." Opportunity zones can be found in both rural and urban communities, and in all 50 states.

5. Birmingham has nearly 5,000 tax delinquent properties. Properties that have been in delinquency more than 5 years can be cleared of these taxes and liens and banked for future development.

Towards a New Studio Pedagogy: Improving Social Determinants of Health through Community-based Participatory Research and Design

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ABSTRACT: The social determinants of health (SDOH) are cited as a common reason for disparities in public health and social medicine literature. However, the interlinkage between SDOH, such as neighborhood and built environments with healthcare access and quality, education access and quality, economic stability, and social and community context, is less explored and is handled independently. Therefore, this research asks what role design-based interventions play in improving SDOH. The method includes a combination of quantitative and qualitative approaches completed by the author with multiple collaborators and built upon their previous works before the multi-year senior-level studio investigation began. Using the prompts from these works, the studio integrated the community-based participatory research (CBPR) model and Jamie Learner's urban acupuncture approach to examine the role of design-based interventions for low-income black communities in Cincinnati, OH. The main contribution of this work is repurposing existing vacant lots and buildings to improve spatial, social, and service environments by integrating them with the existing community fabric via proposing programmatic gaps and improving the connection between SDOH. Over thirty individual design interventions are proposed, ranging from short (1-year), mid (1-3 years), and long-term projects (over 3 years), including fixing existing structures, green infrastructure, and community gardens, and new building projects hosting various community functions, such as a community clinic, pharmacy, zero-energy homes, co-op grocery store, education, and training center for renewables. Integrating individual interventions with the existing community's physical, social, and economic structure provides opportunities to mitigate the impact of extreme weather events and improve SDOH while making it actionable research. Currently, community partners are pursuing these projects with the help of academic, civic, and industry partners by seeking external funding (such as the EPA EJ grant) and availing the existing state-funded programs. Progress is slow but steady, and financial challenges remain a primary barrier.

KEYWORDS: Social determinants of health, design-based interventions, community-based participatory research, urban acupuncture, low-income communities

INTRODUCTION

Economically deprived communities face the burden of health disparities in urban areas (CDC). The quality of social determinants of health (SDOH) – neighborhood and the built environment, health and health care, social and community context, education, and economic stability – in a given area are commonly described in public health and social medicine literature as a cause of these disparities (CDC). Environmental conditions caused by degrading physical environments have a significant influence on physical and mental health (North et al. 2004, Brokamp et al. 2017); and lack of social and service environments (like access to health care) further increases negative health impacts (Diez Roux and Mair 2010, Duncan and Kawachi 2018). Infants and children, older populations, pregnant women, individuals with chronic medical conditions, and outdoor workers are most vulnerable (Bei et al. 2013, CDC). Demographic factors like race, gender, age, and income are frequently cited denominators for negative health (Claudio, Stingone, and Godbold 2006, O'Neill 2005). In addition, changing climatic impacts — the increasing frequency of extreme weather events (EWE), particularly heat waves and flash flooding — worsen environmental exposure in low socioeconomic status (SES) communities (Ahdoot 2015, D'Amato et al. 2015, NIEHS 2014), further increasing health disparities. Importantly, climate change-related deaths and illnesses are preventable (CDC). Although community responses to health outcomes are not consistent (Beck et al. 2014) and vary per geographic location, the community-specific context plays an important role.

SDOH are commonly studied in both social medicine and public health, but the inflections this concept receives in each disciplinary context are different. John Ryle suggests that social medicine differs from public health in three distinct ways (Horton 2013). First, it fundamentally concerns itself with people and endeavors to study them in relation to their environment, whereas public health primarily focuses on the environment. Second, social medicine has a broader reach, which, unlike public health, includes non-communicable diseases, mental health, and injuries. Third, social medicine takes into account the organization of after-care and the readjustment of the lives of individuals and families disrupted or broken by illness. Within the dichotomy of social medicine and public health, this paper presents design as a preventive medicine tool that can shape the physical, social, and service environment in order to create livable, healthy, and resilient communities and minimize health disparities.

In the context of an urban design studio engaging in this work, pedagogical questions about the role of architecture (specifically, design interventions in the existing context) in improving physical and mental health in low SES communities are paramount. The importance of Jane Jacobs's work on how the built environment influences people and how they navigate their neighborhood is a point of departure for this approach (Jacobs 1961). Jacobs notes that urban design and planning should encourage a diversity of destinations that would attract visitors throughout the day and night, and she foregrounds the importance of creating or enhancing often-used gathering spaces that engage residents of all ages, providing welcome opportunities for daily physical activity and social interaction (Duncan and Kawachi 2018). Recently emerging healthy design guidelines, like *Building Healthy Places Toolkit: Strategies for Enhancing Health in the Built Environment* (ULI 2015) and *Healthy Community Design Checklist Toolkit* (CDC) reflect these principles.

1.0 METHOD

Adopting the CBPR model, this studio co-designed interventions with residents, a community-based non-profit organization, and the community council as project partners since the inception of the studio. It prioritizes community-based health issues intensified by extreme weather events and research and design questions emerging from such partnerships, contrasting with imposed agendas by status quo top-down approaches. A combination of qualitative and quantitative research methods provided a deeper understanding of how extreme weather intensifies physical and mental health impacts. A health survey completed by the collaborators provided residents' perceptions of their indoor and outdoor environment and its health effects as a part of their daily lifestyle (Cincinnati, 2016). Analysis of the physical environment identifies several microenvironments in the community that residents overlap (Bhiwapurkar, 2017). A field study conducted for this purpose confirms hazardous environmental exposure via recording environmental stressors along the path commonly traveled by residents. The urban acupuncture approach, grounded in a deeper understanding of problems, people, and place, further informed current gaps in physical, social, and service environments affecting SDOH. To revive the community's spatial, social, and service environment, the studio proposed design interventions to fill in community programmatic gaps, improve urban landscape and outdoor spaces, and build community pride via art and culture-based activities. The integration of design-based interventions with existing community fabric on strategically selected vacant lots and buildings using the urban acupuncture approach, as a part of the studio pedagogy, engages diverse groups, interests, stakeholders, organizations, and agencies to work simultaneously on an overarching goal of creating healthy, equitable, and sustainable solutions.

1.1 The community context

The selection of a representative of the low SES community was an essential first step in this process. The selected community, South Cumminsville (SC), is the smallest of the 52 neighborhoods that constitute the City of Cincinnati—located in the Lower Mill Creek Valley, SC (Tract 77, BG 2 and Tract 78, BG 3) within a heavily industrialized corridor packed with water management, transportation infrastructure, and a large public housing community. Historically, it was a working-class neighborhood within walking distance of manufacturing jobs and community amenities. Still, its recent fate is familiar to many industrial urban centers across the Midwest region. SC was significantly impacted by the construction of the I-74 highway, which effectively divided the Cumminsville neighborhood into North and South segments, precipitating racial segregation. While the North segment experienced pronounced development since the partition, SC has struggled with poverty for more than 40 years, and the declining economic and environmental conditions have taken their toll on the community and its residents. Per the 2010 census, the population of 3,319 residents is 92% African American or multi-racial. The community has a 25.5% unemployment rate, compared with Hamilton County's unemployment of 6.1% (2010 US Census). Life expectancy in SC is 72.1 years compared to 87.8 years in Cincinnati's more affluent neighborhoods. The average median annual household income is $17,185, about 1/3 of the county's $50,990 median. Women head 62.7% of the 1,431 households, compared to 20.8% of county households.

As of 2010, more than one-quarter (26.1%) of the neighborhood's homes were vacant (US Census 2010). Many were bank-owned Real Estate Owned (REOs) or held by out-of-state investors. Many of these houses have been demolished in the past couple of years, and vacant lots have grown. However, public dollars available for rehabilitation and new construction remain limited. The land use is distributed between residential and industrial functions, with minimal buffering. Many factories are now shuttered, resulting in a high percentage of brownfield sites. Additionally, the community currently lacks access to basic functions within walking distance, experiences a food desert situation, and remains isolated from the north segment.

SC was selected as a test case because it represents other city communities experiencing decades-old development policies (such as redlining, segregation by freeways, industrial land use, and more). The community also expressed interest in the new ideas to be proposed by the studio and was eager to integrate design-based interventions as a part of the community development process. While the neighborhood faces many challenges, residents actively engage with the SC Community Council (SCCC) and the resident-led SC Action Team (SCAT). A community-based non-profit organization, Working In Neighborhoods (WIN), partners with the SCCC & SCAT has a mission “to empower people to make informed choices for themselves and their neighborhoods through Community Building, Home Ownership, and Economic Learning.” WIN has built partnerships with community actors like the Ethan Taylor Elementary school, the neighboring Millvale Rec Center, First Baptist Church of Cumminsville and other churches, and a small but dedicated core of local businesses. They also work with the City of Cincinnati, such as the Environment & Sustainability, Recreation, Transportation, Planning, and Community & Economic Development departments. SCCC & WIN sponsor youth summer and afterschool programs, a community garden, and regular community-building events. They are key partners on this project.

This partnership between WIN, SCCC, and SCAT has led to several achievements: several pedestrian safety improvements; changes to the City's Land Development Code that reflect community priorities; a HUD designation as a Neighborhood Revitalization Strategy Area; bringing job training resources through the City's "Hand-Up" Initiative; securing major upgrades for the recreation area and the community garden; construction of a Greenway Trail along the Mill Creek; and expanding fresh food access through the Healthy Corner Store initiative & a weekly "Harvest Day" to sell locally grown organic produce. There existed an opportunity to integrate these ongoing independent interventions in addition to the programmatic needs that are meaningful to the community.

1.2 Establishing a connection

A community is a complex system composed of individuals, interests, experiences, and sectors requiring preparation and guidance as a precursor for successful engagement. Following the protocol suggested in NIH's community-engaged research model(Michener et al. 2012), the faculty instructor attended several community meetings and events and worked with a team of city officials and health researchers involved in the community in order to become familiar with the context and gain the trust of residents and community partners. WIN and SCCC members were welcoming and became primary contacts for the project. Interacting with the community context, residents, and working groups to understand community concerns and ongoing projects is crucial for community-engaged research (Michener et al. 2012; Ebi and Semenza 2008). Understanding the complex community context allowed the faculty instructor to effectively frame the health-focused studio problem, pursue research needed to build on ongoing efforts, and identify ways to shape the studio projects to make them meaningful for the community.

1.3 Community-based participatory research

A combined qualitative and quantitative research method provided a good understanding of the role of the physical, social, and service environment in shaping community health, particularly during extreme weather events (Bhiwapurkar et al. 2018).

1.3.1 Qualitative research

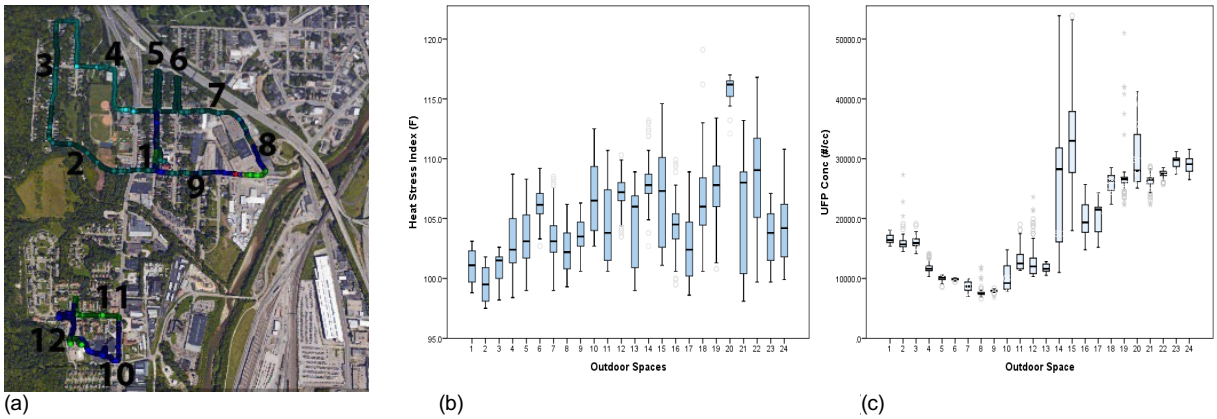
A health survey (n=118) was conducted via Project Cool It (awarded to the City of Cincinnati), funded by the EPA's Agency for Toxic Substances and Disease Registration, in 2014-15 in Mill Creek Valley communities, including SC, to establish a baseline for community health. Demographic information about race/ethnicity, age, and gender were collected, and respondents were also asked to report their occupancy status (rent/own). The average length of residency was 18.8 years; moreover, 52.2% (n=64) owned their own homes, 48.8% (n=52) rented, and the remaining data (from two residents) were missing. This trend is consistent with the 2010 Census data. The survey results are similar to other published work (Khan et al. 2019). In addition, respondents were asked about their perceptions of their indoor and outdoor environments so that researchers could investigate how self-perception of the environment might affect reported health outcomes. Given the lack of perceived mental health data, this line of investigation was an important prerequisite in assessing the role of future interventions. 61.5% (n=72) reported feeling irritable in the summer due to the heat, and 41.9% (n=56) and 42.1% (n=48) of the residents cited summer heat as the cause of changes to their mood and general health, respectively. Approximately 30.8% reported having asthma or another lung disease, and while 75.4% (n=89) described owning an air conditioner, only 69.5% (n=82) indicated that they used their air conditioner in the summer months. Four residents cited the cost of electricity as their reason for non-use. The majority, 60.3% (n=70), reported spending less than nine hours a day indoors during the summer months. Importantly, parking lots and vacant lots were used as playgrounds by, respectively, 42.7% (n=50) and 35.7% (n=41) of the children. The majority of residents reported living within a one-block radius of a vacant building or lot and/or spilled chemicals. There was a greater level of variability in the respondents' self-perception of the outdoor environment; in particular, 56.8% (n=67) reported that greenspace was available to them, and 87.1% felt safe walking in their neighborhood during daylight hours.

1.3.2 Quantitative research

A geo-medicine-based study conducted by Cincinnati Children's Hospital and Medical Center (CCHMC) researchers shows that not only low SES communities carry the burden of health disparities, but also there is variation among those communities (Beck et al. 2014)). Asthma-related emergency department (ED) visits are very high; low SES communities, including those selected for this study, have a higher concentration of ED visits than more affluent communities. The selected community also reported higher heat-related health problems in the health survey. The faculty instructor then carried out a field study during an extreme heat event in 2016 using a traverse method in which residents' environmental exposure, heat stress index (HSI), and ultrafine particulate (UFP) matter along the commonly used paths and spaces are recorded as shown in Figure 1 (Bhiwapurkar 2017). This study's unique feature includes identifying 24 microenvironments (like street intersections, community spaces, parking lots, etc.) within the community that residents frequently use.

Environmental stressors—heat stress index (HSI) and air pollution—varied across space and time. Among 24 microenvironments in the community, 54% had HSI values in the danger zone (104ºF–124ºF), while 46% were in the extreme caution zone (91ºF–103ºF), per the National Weather Service (NWS 2017). High HSI values were accompanied by ultrafine particulate (UFP) exposure, especially near industrial zones, intersections, and parking lots. Based on an average five-minute walk, residents were in the danger zone 70% of the time and in the extreme caution zone 30% during extreme heat events. UFP exposure ranged from 7,633 to 34,751 particles/cm³ between high- and low-canopy streets with higher traffic exposure. Land use and land cover analysis showed that industrial buildings, large parking lots, and vacant parcels with demolished structures increased impervious surfaces. Streets leading to residential areas lacked tree canopy, heightening environmental exposure, while brownfields added

complexity to the site. These elements intensified heat stress (Bhiwapurkar 2017) and contributed to surface runoff, flash flooding, and sewer overflow during rain events—leading to increased respiratory illnesses (Brokamp et al. 2017).



(a) (b) (c)

Figure 1: (a) Microenvironments (b) HSI spatial distribution and (c) UFP spatial distribution. Source: (Bhiwapurkar 2017)

Outdoor spaces commonly used for social gatherings and children's play, such as parking lots of housing complexes and areas near street intersections, had high HSI values and health-damaging conditions. Indoor spaces didn't offer refuge either; tenants without air-conditioning (or unable to use it due to cost) often spent time outdoors, exposing themselves to heat, air pollution, and allergens. The evidence in this study offers insight into how and why reported heat-related physical and mental health issues—such as irritation, mood swings, and negative health perceptions—are prevalent in the health survey

2.0 DESIGN INTERVENTIONS

The community development history, resident narratives, and research provided critical insights to frame the health-focused studio prompt. Initial analysis of the community's physical, social, and service patterns was crucial to understanding how, where, and why residents get exposed to heat and air pollution in space and time (Figure 2), complementing the above research. Further, the community charrettes proved vital in understanding immediate questions, like how a lack of community function is affecting their daily lives and how design interventions could be integrated into the socio-cultural life of the community, along with more wide-ranging issues, like how the residents perceive the future of their neighborhood and the unique identity they wish to establish for the community. This led to a studio strategy of multiple design interventions at multiple scales spread over short (1 year), mid (1-3 years), and long-term (over 3 years) projects. The dispersed vacant lots and buildings emerged as opportunities to keep them within walking distance.

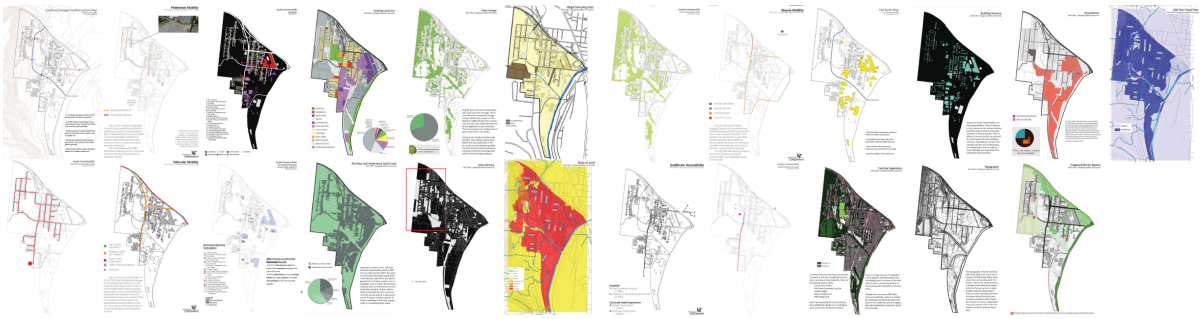


Figure 2: Physical, social, and service patterns within the community context completed during the Fall of 2016. Source: (Bhiwapurkar 2016)

The urban acupuncture concept, grounded in a deeper understanding of problems, people, and places, provided a strategy for integrating design-based interventions. First introduced by Learner (Lerner 2014) and further developed by Sol-Morales (Solà-Morales i Rubió, Frampton, and Ibelings 2008) and Casagrande (Casagrande 2015), this is the first study to apply the concept to improving SDOH. The interventions, representing "needles" shown in Figure 3, were driven by health criteria supported by function and access. New community functions—primary healthcare facilities, mixed-use development, locally owned businesses, diverse housing, healthy homes, and a community center supporting jobs and amenities—were co-designed with community partners. These are integrated into the existing fabric and located within walking distance of each other and public transit. Additionally, Green Parklets (Figure 4) were introduced to address heat, air pollution, and runoff at gathering spaces. The green infrastructure network—community garden, recreation area, and parks—creates a safe, walkable neighborhood usable by all ages throughout the day. These ecologically sensitive design principles complement ULI's Building Healthy Places guidelines (ULI 2015). Pride-building activities, like painting murals on walls and streets, were also included.



Figure 3: Urban acupuncture showing select design-based interventions from studios completed in 2016 and 2017. Source: (Bhiwapurkar 2017)

This studio developed over thirty design-based interventions for improving SDOH that are integrated into the community fabric (Figure 3 shows select projects). While the detailed descriptions of individual design processes are beyond the scope of this paper, a Green Parklet design (short-term) provides an excellent example of improving social spaces while providing shade, increasing native vegetation to arrest air and noise pollution, and decreasing surface runoff by collecting water. Such structures could be located along the walkways in the community (see Figure 4) and used by children and adults alike. For example, the locally owned Mr. Gene's hot-dog place at the intersection of Beekman St. and Dreman St. is a major social hub. At the same time, public housing a couple of blocks further north is popular for children, parents, and grandparents. Similarly, tiny, affordable, healthy homes (mid-term) are proposed to improve homeownership with WIN's support and guidance. The modular designs of these structures simplify the building process for residents and take ownership of the interventions.

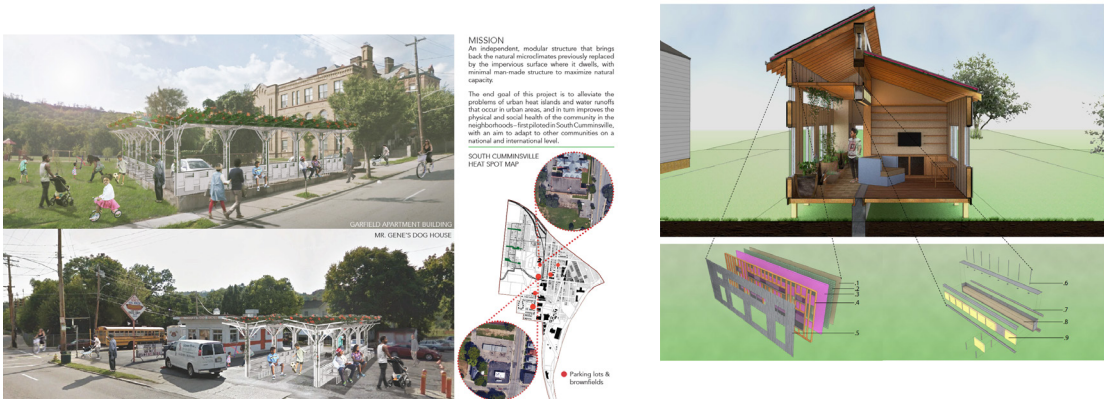


Figure 4: Green Parklet by Trang Le (left) and Healthy Home by Josiah Ibert (right), Fall 2016**.** Source: (Bhiwapurkar 2016)

A complete, safe, and walkable *neighborhood and built environment* allow residents to meet their needs in the community. It has a significant influence on the *social and community context* by energizing public and block-level spaces, like gathering places and community gardens, and improves social interaction among all ages while strengthening social capital and esteem. Reinforced social ties allow residents to live in a close-knit community and ameliorate health concerns (Diez Roux and Mair 2010). Residents feel that they can age in their community without having to move away (several families migrated to other locations when social and service environments deteriorated). A proposed primary health center is vital to improving *health and healthcare access*.

The studio team provided *education and training* on the impact of extreme weather events on physical and mental health. Such training included firsthand experience in recording outdoor and indoor HSI. Residents were provided with a National Weather Service (NWS) Heat Index map to associate empirical data with their perceived health. They were also provided with explanations of how using parking areas as play lots increases HSI. In addition, WIN emphasized the need for health- and energy-efficient homes, along with possible financial training and support. The first net-zero energy housing project is already significantly impacting residents' attitudes toward the environment. The proposed green technology training and education center will also create job opportunities in renewable energy and urban agriculture. There is a possibility of introducing this knowledge at K-8 levels.

Economic stability is the most challenging part of improving SDOH. Job creation and economic development are well beyond this paper's scope as they depend on external sources. However, engaging stakeholders from the community and external funding agencies is key to improving potential investment opportunities in meaningful locations for the residents. For example, mixed-use development and locally owned and operated businesses provide opportunities for investment from within the community. The residents are concerned about gentrification associated with economic development (Checker 2011), as other city neighborhoods, like Over the Rhine, experienced similar fates. The recreation and community centers are expected to provide job training and employment for youth and unemployed residents. A green technology center for renewable energy, urban agriculture, reuse, and recycling is a relatable example in the city for creating a workforce where residents can train and educate members of the community and beyond.

Although addressing SDOH is a transdisciplinary, multi-organizational, and multi-year effort, this studio approach provides a workable blueprint and strategic collaborations. This is important because several independent efforts exist in SC but are not coordinated, diminishing their effectiveness for their intended communities. Therefore, a comprehensive resident-centric, resident-led development plan focusing on improving SDOH via design-based interventions at multiple scales makes this approach unique and applicable to other communities, particularly those with a shared history of economic decline with SC.

3.0 OUTCOME

A community-based participatory research and design pedagogy provides new directions for addressing SDOH using design-based interventions within the myriad of public and social medicine approaches. This pedagogy applies to communities experiencing health disparities and degraded physical, social, and service environments in regional, national, and international contexts. Furthermore, this paper sheds light on several epistemological questions for architectural studio pedagogy on the role of architecture in improving physical and mental health in low SES communities and how design-based interventions can help improve degraded urban systems and damaged ecological conditions. The paper also shares insights on the community-based participatory research and design process to understand health gaps and introduce interventions to improve SDOH. Significantly, this studio pedagogy provides a service-learning model while discovering the potential of design as a tool for addressing social and environmental injustice.

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SUSTAINABLE ARCHITECTURE

Spindletop's Industrial Heritage: The Socio-Economic and Environmental Impact of Petroleum Development in Southeast Texas

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ABSTRACT: The 1901 oil discovery at Spindletop marked a pivotal moment in the economic and industrial evolution of Southeast Texas. Once reliant on the lumber and cattle industries, the region rapidly emerged as a powerhouse of global petroleum production, redefining its economic trajectory. This study examines the far-reaching impacts of Spindletop, exploring how it reshaped the social fabric, urban development, and environmental landscape of key cities such as Beaumont, Port Arthur, and Orange. Framing the oil boom within broader discussions on industrial heritage, this research also examines the role of the Spindletop-Gladys City Boomtown Museum in preserving and interpreting this pivotal chapter in history. Utilizing a qualitative approach, the study weaves together archival research, oral histories, and spatial analysis to track patterns of urban growth and industrialization following the oil boom. Additionally, environmental assessments provide insight into the long-term ecological consequences of petroleum-driven development, offering a critical perspective on the region's industrial legacy and its relevance for sustainable futures. The trajectory of Spindletop serves as a microcosm for broader global energy transitions, highlighting the persistent tensions between economic expansion, resource dependency, and environmental responsibility. By revisiting this history, the research underscores the urgent need to balance industrial progress with ecological sustainability in addressing today's energy challenges.

KEYWORDS: Spindletop Oil Discovery, Southeast Texas Transformation, Urban Development, Environmental Impact, Heritage Preservation

1.0 Introduction

On January 10, 1901, a remote hill near Beaumont, Texas, erupted in a torrent of crude oil, forever altering the course of industrial history. When the Lucas Gusher erupted at Spindletop, a torrent of oil blasted into the sky with staggering force, gushing nearly 100,000 barrels per day. This unprecedented event not only captivated the world but also ignited the modern petroleum industry, forever altering the global energy landscape (Graham and Marvin 2001). This singular event not only reshaped Southeast Texas but also set the foundation for the United States' ascent as a global energy powerhouse. Before Spindletop, Texas remained largely agrarian, with its economy reliant on cotton, cattle, and timber. The discovery of vast oil reserves shattered this rural identity, triggering an economic and demographic explosion. Beaumont, once a sleepy settlement, became a magnet for speculators, laborers, and industrialists seeking to capitalize on the newfound resource wealth (Casey and Mehan 2023). The chaotic early boom, characterized by hastily erected wooden derricks and unregulated drilling, eventually gave way to a more structured urban and industrial landscape. Oil refineries, transportation networks, and corporate enterprises emerged, cementing the region's role in fueling industrial expansion across the country (Mehan and Casey 2024; Hardwicke 2008).

Spindletop's influence extended far beyond economic prosperity. The overwhelming scale of the gusher exposed critical gaps in drilling technology and resource management, prompting rapid innovation. Engineers and geologists pioneered new extraction techniques, leading to more efficient and controlled oil drilling methods that would define petroleum engineering for decades to come (Choguill 1996). More significantly, Spindletop transformed oil from a niche commodity into a dominant energy source, fueling automobiles, mechanized industries, and global trade networks (Casey and Mehan 2024; Larkin 2013). Even today, Spindletop's legacy reverberates through energy policy, industrial development, and environmental discourse. The field that once symbolized limitless economic potential now serves as a reminder of both the transformative power and the ecological consequences of fossil fuel dependence. As energy transitions gain momentum, the lessons of Spindletop remain relevant in shaping discussions on sustainability, innovation, and the future of global energy systems.

2.0 Industrial Heritage and Genesis of Southeast Texas

In the southeastern corner of Texas, where history, industry, and culture intersect, lies the Golden Triangle—a region shaped by the dynamic cities of Orange, Beaumont, and Port Arthur. Over the years, this trio has been instrumental in defining Texas' economic and industrial landscape, evolving from early trade hubs into a powerhouse of commerce, energy, and innovation.

Situated along the Louisiana border, Orange is the eastern gateway to the Golden Triangle, a city rich in history and deeply committed to preserving its heritage. Its prime location on the Sabine River shaped its early development into a vital hub for trade and transportation, leaving a lasting imprint on the region's economy. Today, Orange balances industrial progress with environmental stewardship, exemplified by the tranquil beauty of the Shangri La Botanical Gardens and Nature Center, where towering cypress trees and vibrant azaleas create a serene natural retreat. This commitment to sustainability and education reflects the city's broader vision. Museums and historic sites further highlight Orange's role in shaping Texas' early development, ensuring its rich past remains a guiding force for the future. Moving westward, Beaumont stands as the industrial anchor of the Golden Triangle, its trajectory forever altered by the historic Spindletop oil discovery in 1901. The resulting boom transformed the city from a modest agricultural community into a bustling economic center, drawing entrepreneurs and workers in droves. Today, the Port of Beaumont remains one of the nation's busiest shipping hubs, driving global trade, while institutions like Lamar University help develop the skilled workforce essential for sustaining the region's economic vitality. Despite its industrial backbone, Beaumont is also a city of cultural depth, exemplified by landmarks like the McFaddin-Ward House Historic Museum, which serves as a reminder of its rich heritage amid ongoing growth.

Port Arthur, a vital gateway on the Gulf of Mexico, has been a cornerstone of the global energy industry for over a century. Shaped by its deep-water port and expansive refinery network, the city has long served as a critical hub for petroleum production, processing, and international trade. Home to North America's largest oil refinery, operated by Motiva Enterprises, the city is deeply tied to international commerce. Its economy has weathered both downturns and natural disasters, yet each challenge has been met with resilience and reinvention. Beyond its industrial significance, Port Arthur boasts a diverse cultural history, celebrated in places like the Museum of the Gulf Coast, which highlights the city's impact on Texas' industrial and cultural legacy. With its deep-water port facilitating vital imports and exports, Port Arthur remains a crucial link in the nation's supply chain. Orange, Beaumont, and Port Arthur each possess their own unique identities, yet their histories are woven together by a legacy of adaptability, shared progress, and enduring resilience. The Golden Triangle has grown into a diversified economic hub, encompassing petrochemical production, manufacturing, global shipping, and emerging renewable energy sectors. As infrastructure demands rise, regional leaders recognize that their continued success depends on cooperation, ensuring that shared challenges—whether related to climate resilience or economic diversification—are met with forward-thinking solutions. Looking ahead, the Golden Triangle stands at a crossroads of opportunity, with sustainability, technological innovation, and cultural preservation shaping its future. The spirit of resilience and ingenuity that has defined Orange, Beaumont, and Port Arthur for generations continues to drive Southeast Texas forward, ensuring that this historic region remains a force of industry, heritage, and progress for years to come.

3.0 Transitioning Industrial Landscapes: From Oil Age to Sustainable Futures

The 20th century was defined by the dominance of the petroleum industry, an era that reshaped economies, urban landscapes, and global geopolitics. Oil became synonymous with progress, fueling transportation, powering industries, and dictating infrastructural expansion (Mehan and Abdul Razak 2022a; 2022b). The proliferation of refineries, pipelines, and industrial zones underscored the economic ambitions of the time, embedding oil-centric development deep into urban and regional planning. However, as environmental crises and resource depletion intensified, the vulnerabilities of this dependence on fossil fuels became increasingly apparent. The shift from an oil-dependent economy to sustainable energy alternatives marks a defining transition in contemporary industrial landscapes (Silva et al. 2023).

The transition to a post-oil era is not merely a response to ecological urgency but an essential economic and infrastructural recalibration. Governments and industries worldwide are rethinking energy policies, shifting from extraction-based models to regenerative and carbon-neutral strategies (Mehan and Abdul Razak, 2022c). This transformation presents multifaceted challenges, from mitigating economic instability in oil-reliant regions to reconfiguring urban spaces that were historically molded by petroleum-driven economies. Yet, these shifts also present opportunities to embrace a diversified energy matrix, where renewable sources such as solar, wind, and hydroelectric power redefine industrial operations. Technological advancements in smart energy grids, circular economies, and net-zero infrastructure are reconstructing the framework of industrial and urban development, emphasizing resilience over depletion (Boodaghi et al. 2022).

The spatial consequences of this transition are particularly pronounced in urban environments (Mehan, 2020b; 2021). Cities once shaped by oil wealth and rapid industrialization must now navigate a paradigm shift that prioritizes sustainability and social inclusivity. Post-oil urbanism envisions cities as ecosystems that harmonize built and natural environments. These future cities are not merely sites of economic activity but act as testbeds for ecological and technological experimentation, integrating biophilic designs, circular economies, and low-carbon infrastructures. The repurposing of abandoned oil refineries, industrial plants, and extractive landscapes into green innovation hubs signals a radical departure from previous urbanization models, fostering a more adaptive and ecologically attuned urbanism (Rempins et al., 2018; Star 1999).

Industrial landscapes have long reflected the socio-economic priorities of their respective eras (Mehan 2022). The oil age saw urbanization driven by petrochemical industries, with cities near oil reserves experiencing rapid spatial transformations. The architecture of the oil economy was utilitarian—functional yet symbolic of industrial prowess. Skyscrapers housing energy conglomerates, sprawling refineries, and extensive logistical networks became defining features of petrochemical urbanism. However, these urban typologies often coexisted with stark inequalities, environmental degradation, and unsustainable expansion (Seyedi and Mehan 2024).
Cities such as Houston exemplify the oil age's dual legacy—unprecedented economic growth coupled with pressing environmental and infrastructural challenges. The wealth generated from petroleum industries catalyzed

metropolitan expansion, yet often at the cost of urban livability, social disparities, and ecological harm. Rapid industrialization led to congestion, pollution, and unchecked development, necessitating a reevaluation of urban planning principles. As these cities pivot toward post-carbon futures, they serve as critical sites for reimagining sustainable urbanism (Sánchez-García et al. 2023).

The post-oil transition is not merely an economic shift but an architectural and cultural reinvention. Industrial landscapes, once tethered to fossil fuel dependency, are being repurposed into regenerative spaces that support green economies. Adaptive reuse of industrial heritage sites, integration of renewable energy infrastructure, and community-driven urban development signal the emergence of a new architectural lexicon—one that prioritizes sustainability, inclusivity, and resilience. Investments in green infrastructure, energy-efficient design, and decentralized energy networks are reshaping the built environment, fostering cities that function as dynamic, low-impact ecosystems.

The lessons drawn from the oil age serve as a crucial foundation for this transformation. Rather than erasing the industrial past, post-oil urbanism seeks to integrate historical narratives into contemporary solutions. The shift away from fossil-fuel-driven development is not simply about abandonment but about strategic adaptation—repurposing the existing industrial fabric to meet the demands of a climate-conscious future. The future of industrial landscapes, therefore, lies in their ability to reconcile past excesses with forward-thinking innovation, creating cities that balance economic viability with ecological responsibility. This transition requires an interdisciplinary approach, where policymakers, designers, and communities collaborate to construct a built environment that is both prosperous and sustainable, ensuring that the industrial landscapes of tomorrow embody principles of regeneration rather than extraction.

4.0 The Gulf Coast Region: Navigating Change in an Era of Transition

The Gulf Coast stands at the crossroads of historical legacy and emerging futures, shaped by the interplay of energy transitions, environmental challenges, and infrastructural evolution. As a region historically defined by its role in the oil economy, its trajectory now leans toward diversification, adaptation, and resilience in the face of global shifts.
For decades, the Gulf Coast has been a linchpin of the global energy economy, serving as a vital node in the production, refining, and distribution of fossil fuels. However, as renewable energy gains momentum and geopolitical landscapes shift, the region is experiencing a profound transformation (Gulf of Mexico Data Atlas, 2023). Investments in offshore wind, solar, and bioenergy are redefining the region's economic profile, offering pathways to reduce carbon dependence while maintaining its strategic importance. The challenge lies in balancing legacy industries with future energy imperatives, ensuring economic continuity while steering towards a more sustainable model.

The Gulf Coast's ecological landscape is equally dynamic, characterized by vast wetlands, estuaries, and barrier islands that support diverse ecosystems. Yet, these fragile environments are increasingly vulnerable to climate change, rising sea levels, and industrial encroachment (Mehan 2023). Coastal erosion, intensified hurricanes, and habitat loss threaten both biodiversity and human settlements, demanding innovative solutions to enhance resilience (Mehan and Tafrate 2023). Restoration efforts—ranging from wetland rehabilitation to climate-adaptive urban planning—are critical in securing the region's ecological integrity. Conservation initiatives, informed by both science and local stewardship, offer strategies for mitigating environmental decline while fostering sustainable development (National Oceanic and Atmospheric Administration 2023).



Figure 1: Off-Shore Wind Farm. Source: (The Texas Tribune, 20 July 2023.)

Beyond environmental concerns, the Gulf Coast's infrastructure serves as the backbone of its economy, connecting industries, ports, and urban centers. The region's extensive network of energy hubs, transportation corridors, and industrial complexes faces increasing pressure to adapt to the realities of climate change. Extreme weather events, such as hurricanes and storm surges, highlight the vulnerabilities of traditional infrastructure and underscore the necessity for resilient systems (American Society of Civil Engineers 2022). Investments in storm-resistant architecture, adaptive urban planning, and sustainable transportation networks are becoming imperative. By rethinking infrastructure through the lens of resilience and sustainability, the Gulf Coast can future proof its economic assets and ensure the safety of its communities.

Amid this transformation, the documentation of the Gulf Coast's industrial past remains crucial. The Oil Age, which shaped the economic and cultural fabric of the region, must be carefully archived to inform future generations. This historical record extends beyond technological advancements to encompass the socio-economic narratives of oil-dependent communities. Documenting the rise and decline of the petroleum sector—through photographs, technical blueprints, oral histories, and socio-economic analyses—provides a foundation for understanding how industrial transitions impact society (Weddle 2024). The shift from fossil fuels to renewables presents an opportunity not only to build a more sustainable economy but also to reflect on the lessons of the past.
Technological evolution has played a central role in shaping the region's industrial landscape. From early drilling methods to advanced refinery processes, innovations in energy extraction and distribution have left an indelible mark (Mostafavi and Mehan 2023). Archival efforts should capture these milestones, preserving records that illustrate how technological advancements influenced urbanization, labor markets, and regional economies (Mehan and Mostafavi 2023a; 2023b). Likewise, environmental records documenting oil spills, air and water pollution, and mitigation efforts offer critical insights into the ecological costs of industrial development. These archives will not only serve as historical references but also as tools for policymakers and planners navigating the transition to sustainable futures (Environmental Protection Agency 2023).

The Gulf Coast's evolution exemplifies the broader global challenge of reconciling industrial heritage with sustainability imperatives. As energy transitions reshape economies and environmental pressures demand urgent responses, the region finds itself in a moment of reinvention. The lessons of the past, when carefully documented and critically analyzed, serve as invaluable guides for shaping a future that is both resilient and equitable. By embracing forward-thinking policies, investing in climate-conscious infrastructure, and fostering inclusive economic development, the Gulf Coast can emerge as a model for regions undergoing similar transformations worldwide.

5.0 Further Discussions and Conclusion Notes

As we move beyond the era of oil dependency, we stand on the verge of one of the most profound transformations in modern history. The combined pressures of climate change, resource depletion, and environmental degradation demand not only a shift in energy production but a complete rethinking of how societies operate. This transition extends far beyond technological advancements—it represents a fundamental shift in economic structures, urban planning, policy development, and cultural perspectives.

For over a century, fossil fuels have been the backbone of industrialization and economic progress. Yet, their finite nature and mounting environmental costs have exposed the vulnerability of this reliance, making the shift to renewable energy both inevitable and essential. The post-oil future is not just about substituting one energy source for another; it requires a comprehensive restructuring of global economies to prioritize resilience, adaptability, and long-term sustainability. Renewable energy sources—such as solar, wind, hydroelectric, and geothermal—are not only reducing carbon emissions but also transforming geopolitical dynamics by decentralizing energy production and diminishing dependence on fossil fuel-rich regions. This transformation must also extend to urban environments. Cities, historically designed around the demands of the oil economy, now need to be reconfigured for ecological sustainability. The post-oil city will emphasize green infrastructure, climate-responsive architecture, and decentralized energy systems. The integration of smart technologies, efficient mobility networks, and carbon-neutral buildings will be crucial in fostering urban resilience while balancing development with environmental responsibility. Urban planning must not only prioritize energy efficiency but also ensure social inclusivity, making the benefits of sustainable urbanization accessible to all communities.

Economically, this transition presents both challenges and opportunities. The rise of industries focused on renewable energy and energy-efficient technologies signals significant economic potential, yet oil-dependent economies must navigate the complexities of restructuring their workforce and financial models. The shift away from fossil fuel dominance necessitates proactive strategies, including economic diversification, workforce retraining, and investment in research and innovation. Governments and businesses must collaborate to support workers in transitioning to new industries, ensuring economic equity remains at the core of this transformation.
On a global scale, the shift to a post-oil economy underscores the urgency of international cooperation. Climate change and the need for sustainable energy solutions transcend national borders, making multilateral collaboration essential. Expanding renewable energy infrastructure, sharing technological advancements, and addressing disparities between developed and developing nations will require coordinated efforts. A just transition must ensure that historically marginalized communities are not left behind in the move toward a more sustainable future.

Culturally, the post-oil era is driving a change in societal values, shifting away from excessive consumption toward sustainability and ecological responsibility. More urban communities are embracing local economies, circular design

principles, and regenerative practices that prioritize long-term environmental well-being over short-term profits. This shift is reflected in the built environment, where smart cities are emerging as interconnected ecosystems that integrate architecture, infrastructure, and energy systems to promote both efficiency and community well-being.

Educational and research institutions play a pivotal role in this transition. Universities are becoming innovation hubs for sustainability, developing new architectural methods and energy solutions that challenge traditional models. The next generation of architects, planners, and engineers must be equipped with the skills and knowledge to design a future that moves beyond extractive economies, championing regenerative and sustainable solutions. Rethinking the post-oil era presents both a significant challenge and an unprecedented opportunity. This transition is not just about energy—it is about redefining the systems that shape daily life. If approached with a holistic perspective, it has the potential to create a more equitable, resilient, and sustainable future. By learning from the past and embracing forward-thinking strategies, we can chart a new course that ensures ecological balance, economic justice, and technological progress for future generations.

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Affordances of Architectural Typology

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ABSTRACT:
“Affordances of Architectural Typology" is a concept for design-driven research that explores and advances sustainable design strategies aimed at resilient building structures but are inherently architectural in nature. As material compositions, buildings mediate between forms and functions across different timescales. Considering the “shearing layers” of a building, the primary structural system can last for hundreds of years, while non-bearing walls, surfaces, furnishings, and specific uses are more temporary. This temporal disparity creates a gap that architects bridge “designerly”—using techniques of abstraction to envision past and future forms of inhabitation and alteration, revealing the building’s fundamental character, or type. A resilient structure aligns closely with its type, a formal structure or organizational notion that imparts a recognizable order upon architectural elements. This alignment is evident in historical buildings where load-bearing elements, building volume, and rooms structurally overlap, allowing for centuries of diverse uses and adaptations. However, with modern, energy-intensive building technologies and the separation of the building envelope, this alignment becomes rare. Thus, transforming modern structures convincingly requires greater interpretation and self-determination in design.

This paper examines the affordances of architectural typologies in two directions, reflecting the authors’ expertise. First, affordances are viewed as extensions to the notion of type in architecture, illustrated with reuse projects demonstrating that beyond meeting specific functional requirements, aiming for typological clarity is key to re-establishing architectural quality and providing flexibility for future transformations. Second, for an innovative approach in resilient architectural design, there is a need to update the post-functionalist critique around the notion of ‘type’ as an epistemology of the architectural discipline. This renewal involves reusing and recycling both the knowledge and the materiality of buildings. Understanding and leveraging architectural typologies can lead to more sustainable and adaptable design practices by embracing the inherent flexibility within the temporal layers of buildings. Architects can create structures that honour their historical significance while being capable of accommodating future needs by respecting typological essence and innovating within its framework to foster resilient architecture that is both timeless and adaptable.

KEYWORDS: Architecture, Typology, Affordance, Adaptive Reuse, Resiliency

INTRODUCTION: BEYOND ADAPTIVE REUSE

In the past two decades, adaptive reuse—the practice of saving and transforming existing buildings—has gained significant prominence and evolved into a distinct field of study and practice, separate from traditional building conservation. This evolution is evident in both practical projects and scholarly research. The architectural spectrum, from renowned architects to community-driven initiatives, now embraces adaptive reuse as a thriving and varied practice. Its associated aesthetics have gained popularity among clients and the public, attracting increased attention from architectural and conservation communities. Adaptive reuse addresses urgent urban challenges, cultural preservation, and economic considerations related to the growing and diverse stock of redundant buildings. Policy support for adaptive reuse has expanded beyond heritage protection, with entities like the European Union incorporating it into their agendas. The global push for carbon reduction, driven by the climate emergency, has further propelled adaptive reuse as a preferred strategy over demolition and replacement. Consequently, architectural education has begun integrating adaptive reuse into its curriculum, and the discourse on the subject has become mainstream and relevant. Authors writing on adaptive reuse in the past decade emphasize its crucial role in responding to contemporary challenges. The cultural attitude of "Reduce, Reuse, Recycle" aligns with the ethos of the twenty-first century, where everything is valued for its usefulness, purpose, and authenticity. This mindset has fueled a growing body of literature on adaptive reuse, reflecting its increasing importance. Notable works include those by Stone (2020), Plevoets and Van Cleempoel (2019), Wong (2016), Robiglio (2017), Schmidt and Austin (2016), Jaeger (2010), and Scott (2008). Important nodes in the formation and establishment of an international network of researchers and practitioners are indicated by events such as the recent international colloquium “As Found” by Hasselt University and the Flanders Architecture Institute at Antwerp’s De Singel. Additionally, the annual peer-reviewed publication Trace – Notes on Adaptive Reuse by the research group Trace at the same university highlights ongoing efforts to consolidate and expand this network. Overall, the rise of adaptive reuse reflects a broader cultural shift towards sustainability and the valuing of existing resources. It underscores a growing recognition of the potential to creatively and responsibly adapt the built environment to meet contemporary needs while preserving historical and cultural significance.

Conceptually, interpretations of adaptive reuse vary significantly due to the diverse disciplinary backgrounds, traditions, and agendas of different authors. Some view adaptive reuse as a broad practice within architectural design, while others consider it a specific practice within interior architecture. The ongoing debate seeks to clarify terminology and definitions, but the multitude of terms and interpretations hinders the establishment of a shared foundation for discussion. The relationship between the old and the new remains a central theme, often discussed as a moment of disjunction between form and function. However, there is no conclusive definition of adaptive reuse, as the duality between old and new may exceed obvious material, functional, or cultural oppositions (Lanz and Pendlebury 2022, 255). In response to these complexities, the authors' research project “Affordances of Architectural Typology” proposes a processual approach focused on the design of the “unaltered”. This research explores the central tenets of balancing design work to create a future-proof and enabling background of non-design or typological design—i.e., identifying the affordances resulting from a building’s type. This approach can sometimes lead to a consistent transformation of the existing fabric, aiming to improve its “typological” quality. By advocating for a fundamental and specific architectural design expertise, the project underscores the importance of securing the resiliency of buildings through a deeper understanding of their typological characteristics. This method emphasizes the value of a building’s inherent qualities and aims to leverage them for sustainable and adaptive transformations, ensuring that structures remain relevant and functional in the face of changing needs and conditions.

1.0 ARCHITECTURAL TYPOLOGY

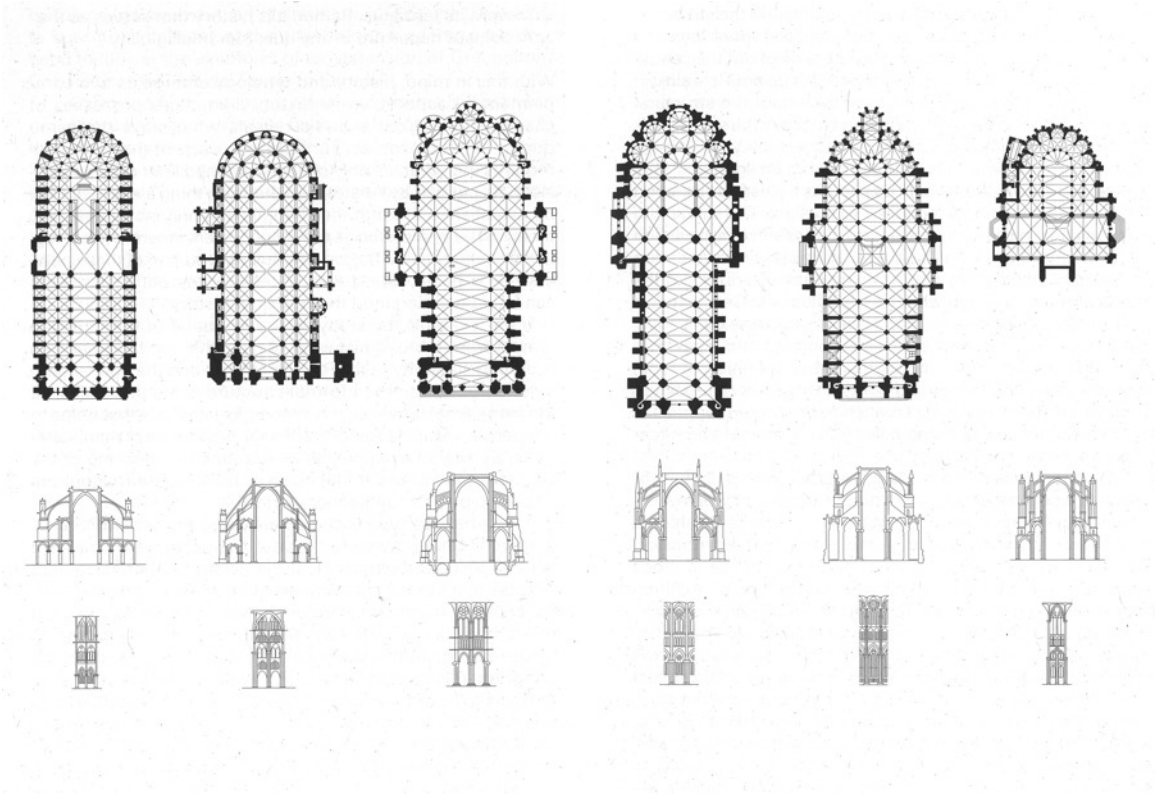


Figure 1: The Great French Gothic cathedrals of the 12th and early 13th century: Paris, Bourges, Chartres, Reims, Amiens and Beauvais. Plans, sections and details. Source: (Martí Aris 2021)

The inconclusiveness of the literature and theory review on adaptive reuse can be compared, with a grain of salt, to the discussions of typology in architecture. The myriad anecdotal cases of adaptive reuse projects resist simple categorization into a neat, undisputed system of types. This issue echoes the question of typology and the nature of architectural work, as explored by the Spanish architect Rafael Moneo in his seminal essay “On Typology” (Moneo 1977). For Moneo, each generation of architects must use ‘typology’ to redefine the nature of architecture and its problems. Typologies, as direct indices of politics, help us understand how even the most mundane aspects of architecture—such as the disposition of primary structures and spatial elements—both determine a subject's experience of space and form the basis for the identification and affordances of given structures. Beyond the pragmatic aspects of repurposing buildings, identifying these affordances as cultural and historical dimensions of the urban environment—and as a repository of architectural form that emphasizes continuity—is one of the central tenets of Aldo Rossi's understanding of type (Rossi 1984). This perspective discredited naïve post-war functionalism and recognized the significance of architectural artifacts in conveying the collective memory of a city. It established the notion that buildings and urban elements are part of a larger urban fabric, not isolated entities. Architectural forms are rooted in historical and cultural contexts, serving as carriers of meaning and collective identity, whether they be buildings, streets, or public spaces. Drawing on these and La Tendenza’s theories, Carlos Martí Arís views type as a condensation of historical experience and codified knowledge without questioning continuous and creative development (Martí Arís 2021). For him, type in architecture presupposes a degree of abstraction that modern thought provides. His thesis that architecture is based on general principles and archetypal forms sees type as an

organizing principle that structures elements through specific relationships. These relationships emphasize the importance of precise architectural terminology and the ability to describe architecture accurately. To further architectural knowledge, it must be viable for description and communication, allowing it to be shared and extended. Typological analysis involves researching and explaining structural similarities that, except perhaps for housing, are not necessarily tied to conventional uses. Thus, observation and comparison are central to typological analysis and to advancing architectural knowledge. Martí Arís distinguishes this typological understanding of structure from semiotic structuralism by showing how types function as elementary architectural structures. He emphasizes that the constant transformation of architecture results from continuous societal change and its longue durée. While identifying typological foundations in modern architecture is challenging compared to the monolithic character of traditional architecture, Martí Arís' conviction remains relevant. He argues that type has not lost its operative capacity in contemporary architecture but should be considered a fundamental condition for actions with outcomes that are not predetermined.

To achieve the important and necessary Vitruvian tenets of sustainability, adaptability, and aesthetic delight—an urgency also expressed by the New European Bauhaus initiative, launched by the European Commission in 2020 to connect the European Green Deal to the desirable quality, sustainability, and inclusiveness of our living spaces—we must rigorously study and teach the ability to assess a building's quality. Enhancing the quality of architecture requires understanding how buildings succeed or fail in terms of sustainability, adaptability, and aesthetic appeal. Despite superficial similarities among buildings, their longevity, flexibility, and careful design vary greatly. The typological analysis proposed here is a comprehensive evaluation of a design's spatial characteristics or a building's physical evidence through thorough architectural analysis. Reflecting the structural context of an existing building, this approach updates and clarifies the role of type today, addressing the responsibility of developing future-proof design solutions for an uncertain future.

2.0 AFFORDANCES

Cross-reading typology with cognitive psychologist James J. Gibson's concept of affordances aims to clarify these design potentials. Affordances respond, on one hand, to the ecological and pedagogical imperative of bringing building adaptation more prominently into the design studio. On the other hand, the concept of affordances helps to define and sharpen an important update of architectural expertise. As Gibson explains, "An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer" (Gibson 1979, 129). This novel perspective on the relationship between the built environment and human perception describes potential actions that the environment enables or affords to an individual, much like being tasked with adapting, renewing, or extending recurring structures. The concept of affordances seeks to understand how people interact with and experience spaces, furniture, or spatial elements and installations. In architecture, affordances refer to inherent qualities of a space or structure that open up numerous possible uses or actions for its occupants, rather than focusing solely on the physical attributes of a building. Gibson's theory emphasizes the dynamic and reciprocal relationship between the environment and the individual, moving away from a purely formal or aesthetic analysis of architecture and exploring how the design of a space interacts with human behavior and perception.

Architectural affordances encompass a range of elements, including spatial configurations, material qualities, and the overall layout of a building, extending these elements to future possibilities. For example, a staircase affords climbing, a door affords opening, and a chair affords sitting. However, these primary affordances (namely, their functional programs) are not solely determined by the physical properties of the intentional objects but can be extended to other elements, such as stairs or window sills for sitting, or pergolas for sun protection and energy harvesting. Affordances are both designed and a matter of the perceptual and cognitive capabilities of the individuals interacting with them. Therefore, the design of a space becomes a language that intuitively communicates potential actions and behaviors to its users. Like Rossi's complex and reciprocal understanding of architecture and the city, Gibson's affordance theory challenges more traditional notions of architectural typology, which tend to categorize buildings based on reductive form-function relationships. Instead, affordances introduce a more dynamic and user-centered approach to understanding architectural potentialities, emphasizing the importance of context in shaping perception and behavior. A space's affordances are not universal but depend on the cultural, social, and individual factors that influence how people interpret and interact with their environment. This contextual sensitivity encourages architects to prioritize spatial qualities over simple functional programs in the design process, fostering a more inclusive and adaptable approach to architecture.

In conclusion, Gibson's concept of affordances impacts architecture theory and typology by shifting the focus from static forms to the dynamic relationship between the built environment and its users. The theory of affordances provides a framework for understanding how architectural elements communicate possibilities for action, influencing human behavior and experience. They extend the understanding of architectural types—constantly recurring structures like linear, radial, domed, reticulated, courtyards, or towers—as past and future building blocks that transcend temporal and geographic boundaries, constantly reused. What once challenged the modernist emphasis on universal principles and its rejection of historical precedents has today become the center of our rational and intuitive attention—the affordances of a building's material composition as a mediation between forms and functions across different timescales. This correlation of architectural typologies with affordances illustrates how a building adapts to or enables different uses and habitation over time. But how is access granted to this index? Is it exclusively through cartographic methods that we can develop this index further? Is it the descriptive combination of text and drawing that empowers us to analyze spatial characteristics and inform design and architectural construction?

3.0 AFFORDANCES OF ARCHITECTURAL TYPOLOGY: A CALL FOR PAPERS (BY DRAWING)

Understanding adaptive reuse solely as an architectural design intervention aimed at repurposing a building, limits its scope and overlooks its transformative agency. Shifting the focus from an oppositional duality between old and new—in terms of both materiality and function—towards viewing adaptive reuse as a process offers a more comprehensive and culturally complex approach. Spatial phenomena that "shift," "translate," or "occupy" hint at the negotiation of architectural form, an ambition that aims to transcend conventional product categories of the market economy.

With our Call for Papers—(Atlas of) Typology Affordances (Postiglione/Lechner 2023)—we were determined to explore the design process of transformation and adaptive reuse through plans, sections, and elevations of buildings, arguing that drawings are central to the forming and transforming, adjusting and reusing of our built environment. To read, write, and negotiate architectural qualities "designerly" means to penetrate and elucidate through qualities and drawing—its abstraction grants us the possibility of envisioning both past and future forms of inhabitation and alteration. It is through drawing that the more vague and unaltered character of a building can be revealed as its type. A resilient structure that seemingly coincides with the building type—as a formal structure or notion of organizing forms that confers a recognizable order upon architectural elements—is conceptualized as "Affordances of Architectural Typology." This coincidence is evident in the strong footprint of historical buildings, where load-bearing elements, building volume, and rooms overlap structurally and allow, along with often generous dimensions, for centuries of different uses and adaptations.

Unpacking the inner character and quality of existing buildings is one of the central goals of the research project "Affordances of Architectural Typology," which evolved from the cooperation of the authors with their respective design and research backgrounds in interior architecture and architecture typologies. The project works towards a publication in the atlas model with additional essays by members of the scientific board. An international call for papers collected projects in three categories—monuments, 19th-century institutions, and more generic or monofunctional 20th-century buildings—and uses an extensive drawing strategy developed by the authors to tell the story of their transformation, highlighting their typological character and resilience. All projects are reduced to the most significant floor plan, section, and elevation. These drawings are always vertically positioned on one single page. They are drawn in their initial phase (black), in the state of demolition and addition (yellow and red), and in the transformed or final stage (black) on separate pages, making the changes over time readable and comparable. Due to older accumulation—of time on the one hand and through physical manipulations on the other—convincing projects tend to feature more pages with transformations and will thus reveal their affordances through alterations of modern structures at the opposite end. This necessitates both more interpretation and more self-determination, as the cases in the third category will show. With this concept, we go beyond a simple recording of qualified building transformations (adaptive reuse) that occurred over time and aim at highlighting reuse interventions that clearly manifest a certain 'typological approach' as a design-driven focus. This is where our investigation distances itself more clearly from the adaptive reuse approach, shifting the interest from a design process generically engaged—though very qualified—with the pre-existing structure (and creatively open to multiple approaches) to one specifically focused on and engaged with its typological qualities (whether present or not).

To identify or unlock the "typological" character as a quality of an existing building or a building reuse beyond its functional and aesthetic dimensions, the key lies in the translation of spatial phenomena into architectural form. It is through mapping spatial relationships and related information—an operation that disrupts traditional architectural coherence—that the architectural process conceptualizes and integrates both time and place, exploring the embedded discontinuity within mapping (Schonderbeeck 2022). Drawing enables the analytic, representational, and speculative use of the architectural process precisely because it suspends a building's connection to time and space. This focus on mapping spatial information through architectural drawing involves creating a spatial ordering system within a map, positioning all ground floors, sections, and elevations vertically on a single sheet. We facilitate the development of a theoretical position in architecture by analytically comparing instances of adaptive reuse within a project. The conceptualization of order extends beyond formal analysis to include spatial disposition, taxonomy, organization, and program through an annotated history in footnotes and references that enable the reader to understand the project's narrative both spatially and theoretically with considerable depth.

This extensive focus on mapping the process of alteration within adaptive reuse projects counters a recently published typology of adaptive reuse by an eminent scholar in the field (Wong 2023). This publication connects fifty seminal adaptive reuse projects to global changes related to energy, manufacturing, agriculture, transportation, religion, and new cultural heritage. This typological order, according to the original context of use, arranges the projects into six chapters where technical and social revolutions explain why certain architectural structures are subjected to reuse. Contrary to Wong's typological atlas, we arrange the projects into three building categories related to their respective architectural types. In the first category, we gather buildings with a strong typological footprint, a spatial quality of monuments or palazzo types. The selected cases in this category show the minimal efforts necessary to harbor new uses. The resiliency and longevity of these buildings coincide with the affordances that the underlying type as a powerful typological footprint provides—sustainability through centuries of adaptive reuse. For example, we provide the complete history of Palazzo Gravina (1549–2023) in Naples, Italy, which was transformed from a private palazzo to a housing block, a public building, and finally to the school of architecture (Figure 2). This category is of extreme relevance to us because it manifests, with great evidence, the "affordances of architectural typology," supporting our hypothesis that clear typological quality strongly impacts the resilience of buildings, going far beyond their original use and suggesting the central role of the building-type concept in a design-driven sustainable approach. Furthermore, when confronting buildings with a strong typological footprint, we

recorded how transformations occurred with minimal interventions, which considerably reduce their carbon footprint, further empowering the sustainable (and purely architectural) qualities of buildings in this category.

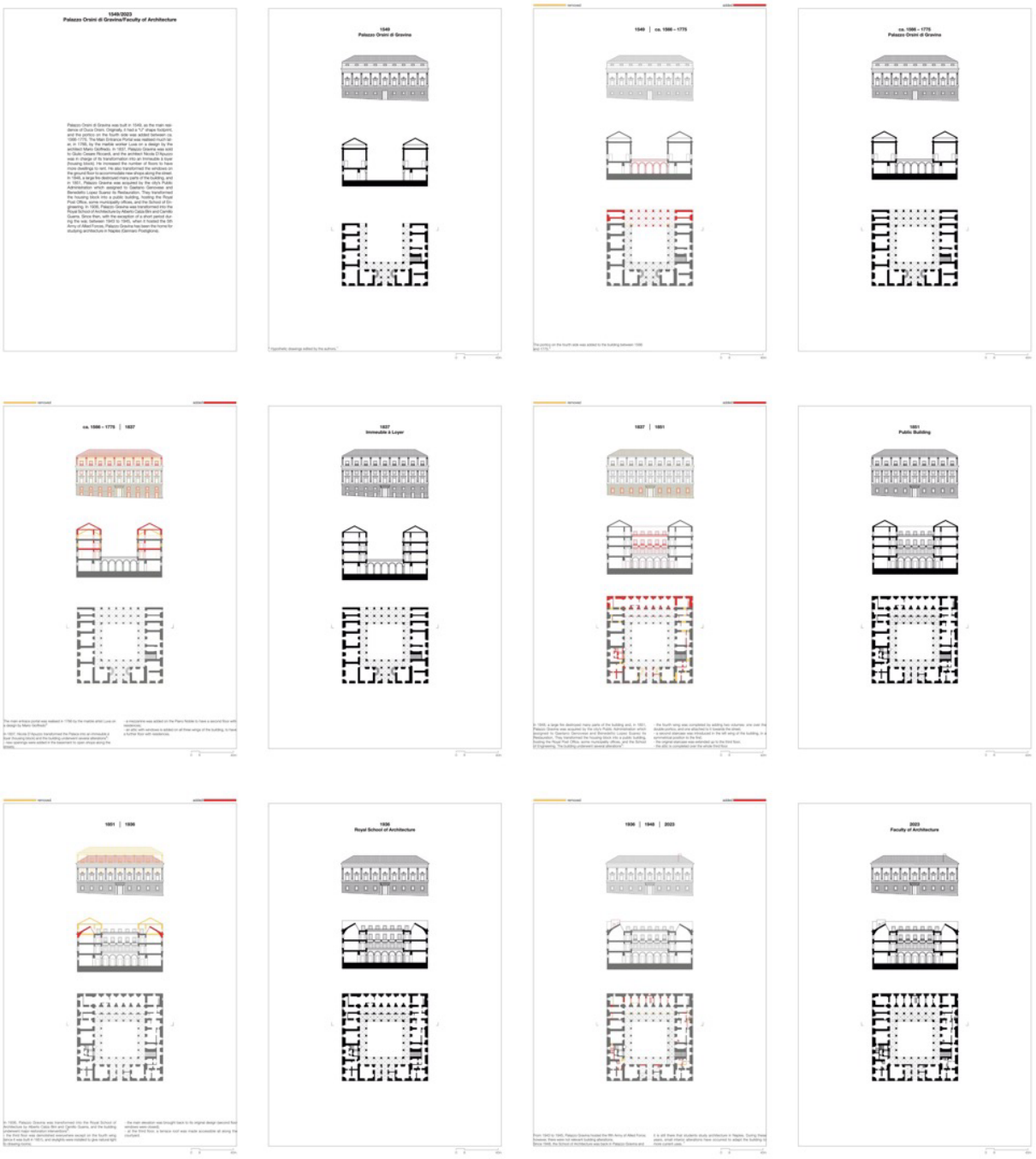


Figure 2: Palazzo Gravina (1549–2023) in Naples (Italy). Monuments, or 'palazzo types', are culturally significant and highly charged buildings that have undergone changes in use and occupation over time while maintaining or enhancing the typological integrity of the building. For example, the Palazzo Gravina in Naples was transformed from a private palazzo to a housing block, a public building, and finally to the school of architecture it is today. Source: (Gennaro Postiglione in Architectural Affordances 2024)

In the second category, we gather buildings with a weaker and/or unclarified spatial quality, primarily from the 19th century. The selected case studies demonstrate significant interventions that enhance and further the existing character of the building, promoting greater resilience through the reduction and clarification of architectural means to minimize the impact of potential future reuses. This category includes the conversions or adaptive reuses of former industrial, infrastructural, military, or health structures. In these cases, interventions change the use of the building but may also alter its typological integrity by adding or subtracting structure. For example, we present the Pousada de Viseu Hotel (1842–2023), formerly the Hospital de São Teotónio in Viseu, Portugal, by Gonçalo Byrne (Figure 3).

The main finding in this category is that transformations aim to fulfil the new functional program while simultaneously preserving and/or enhancing the building's typological quality, even through substantial architectural interventions. Such deep architectural adaptations impart a new resilience character to the buildings—what we have termed "typological affordances"—enabling them to face future repurposing with minimal transformations.

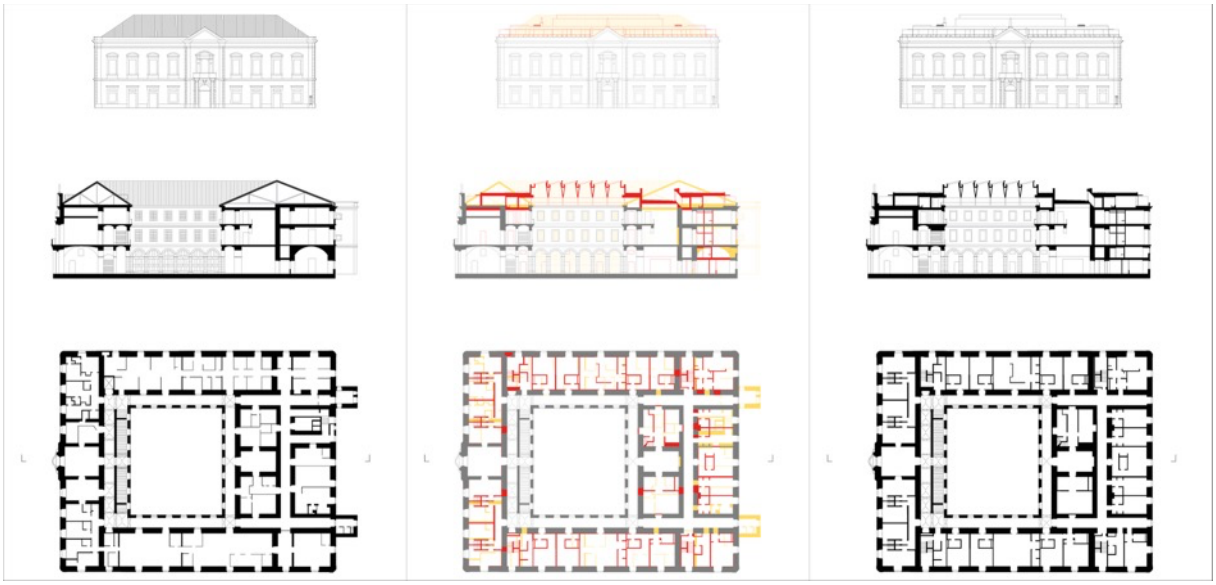


Figure 3: Pousada de Viseu Hotel (1842–2023) in Viseu (Portugal). Institutions, civic buildings, and public buildings, mainly from the 19th-century, are culturally significant structures based on classical compositions. These buildings have undergone significant interventions to improve and enhance their existing character, making them more resilient by reducing and clarifying the architectural means. The interventions alter the use of the building, but they may also affect its typological integrity by adding or removing structures. For instance, the Pousada de Viseu Hotel, formerly known as the Hospital de São Teotónio in Viseu by Gonçalo Byrne. Source: (António Carvalho in Architectural Affordances 2024)

In the third category, we gather case studies where the original spatial quality was nondescript, generic, or even absent—a characterization often found in many monofunctional buildings from the 20th century. Employing a typologically driven design approach, these adaptive reuse projects undergo extensive transformations to imbue them with a new spatial character. This character is typologically significant, illustrating the introduction of a fresh spatial quality that extends the building's lifespan through a new program integrated into its interiors. Within this category, our focus is on examples that initially lacked cultural significance, such as commercial, retail, office, and warehouse buildings. These structures have been transformed to incorporate new spatial qualities that introduce an unexpected level of generosity, facilitating convincing arguments for further adaptive reuse in the future. For instance, consider the ED.G.E. (1973–2022), a mixed-use multi-tenant complex in Milan, Italy, designed by Onsitestudio (Figure 4). The third category prominently demonstrates how reuse interventions guided by a specific typological approach as a design-driven focus can profoundly reshape the building footprint. Beyond merely providing new functionality, these interventions imbue the structure with resilience qualities—termed architectural affordances—achieved through deliberate architectural forms.

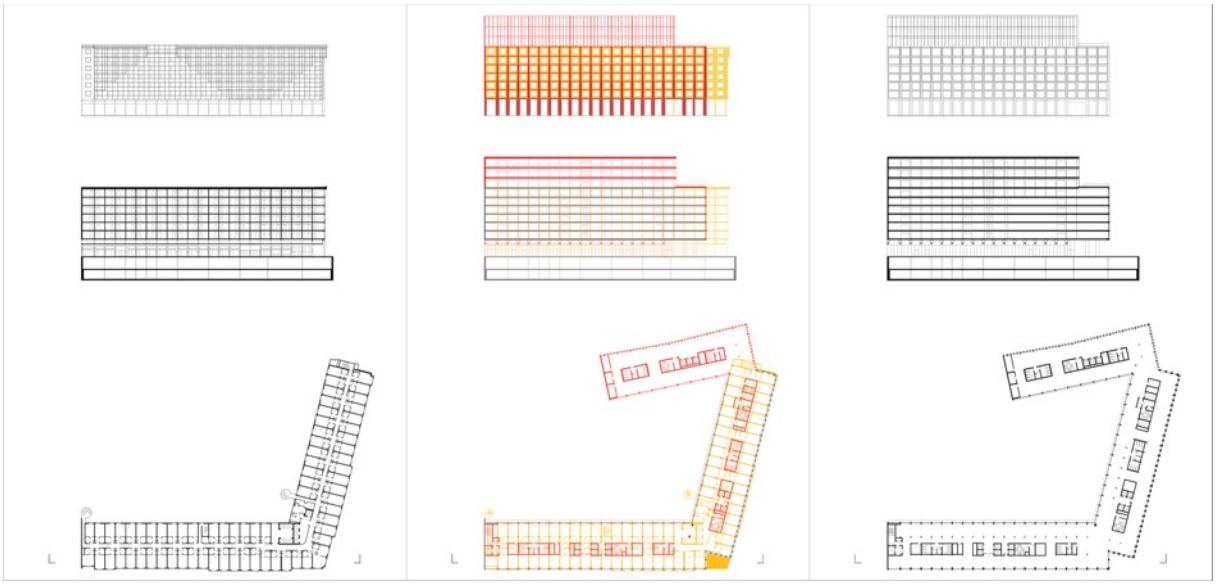


Figure 4: ED.G.E. (1973–2022) in Milan (Italy). The 20th-century monofunctional buildings were initially not culturally charged, but they managed to transform their generic character, which included commercial, retail, office, and warehouse buildings, into new spatial qualities. These qualities add a degree of generosity that was never intended. They now make a convincing case for even further changes in use. As an example, we provide the ED.G.E., a mixed-use multi-tenant complex and former Hotel Aerhotel (built in 1973) in Milan, by Onsitestudio. Source: (Angelo Lunati and Giancarlo Floridi in Architectural Affordances 2024)

CONCLUSION: RESILIENCE BY TYPOLOGICAL CLARITY

The core aim of the Affordances of Architectural Typology project is to elucidate, through an extensive examination of building transformations, two pivotal insights that underscore the nuanced and sometimes conflicting nature inherent in architectural design. Firstly, the project emphasizes that achieving typological clarity extends beyond mere fulfilment of functional necessities. It posits that such clarity is essential for advancing architectural excellence, while simultaneously allowing flexibility for future adaptations. In essence, the pursuit of architectural typological quality necessitates not only adapting structures to current needs, but also fostering a design approach that anticipates and accommodates evolving future functionalities and uses. These seemingly contradictory imperatives are central to our endeavour to enhance building quality, demanding a nuanced understanding of when and how architectural knowledge should be applied to cultivate appropriateness and excellence. Ultimately, this paradigm shift is crucial for fostering a built environment that aligns with the diverse needs and aspirations of contemporary society. Secondly, the atlas and the accompanying essays advocate for an innovative paradigm in understanding and designing resilience in architecture. It argues that revisiting and updating the post-functionalist critique of typology as an epistemological foundation in architectural discourse is crucial for evaluating building quality comprehensively. Enhancing architectural quality requires a deep understanding of how buildings succeed or fail in terms of sustainability, adaptability, and aesthetic appeal. Despite superficial similarities among buildings, their longevity, flexibility, and meticulous design can vary significantly. A thorough evaluation and comprehension of buildings involve scrutinizing rhetorical strategies and descriptions used to bridge the gap between physical presence and socio-cultural representation. Building analysis and typological research can be exhaustive, yet selectively focused on critical junctures where significant revelations provide a comprehensive understanding of the entire structure.

Considering a building's shearing layers, the primary structural system can endure for centuries, while non-load-bearing walls, surfaces, furnishings, etc., are more transient in nature (Brand, 1994). The differing rates at which components of a structure evolve over time influence its affordances. Therefore, designing resilient and adaptable systems hinges on recognizing and accommodating these varying rates of change. Clarifying the core structure and services of a building from a typological perspective facilitates easier adaptation to shifting needs without necessitating extensive overhauls (see Figures 5 and 6). Conversely, elements such as interior spatial planning and decor can be modified more readily and frequently to meet evolving requirements or preferences. The concept that a building, or any complex system, can be divided into layers with distinct rates of change and adaptability significantly enhances potential affordances (Van Ellen 2023). The expansive nature of affordances contrasts sharply with ergonomic or behavioral design studies and approaches, vividly demonstrating how adaptive reuse in architecture intricately intertwines with design evolution over time.

Architecture's efficacy is crucial in offering and realizing these affordances, shaping designs that endure while accommodating a diverse range of functions and uses, ultimately achieving a form of "spatial resilience." This design principle embraces sustainable and efficient utilization of built environments, revitalizing structures that may have become obsolete or underutilized. Sustainability emerges as a primary driver of adaptive reuse, as architects contribute to reducing construction-related waste and conserving resources by repurposing existing buildings. This approach resonates with contemporary environmental awareness, minimizing the ecological footprint associated with traditional construction practices. However, the cultural responsibility of architecture extends beyond physical transformations and functional fulfilment in adaptive reuse contexts, striving always to achieve a harmonious relationship between typology and urban form.

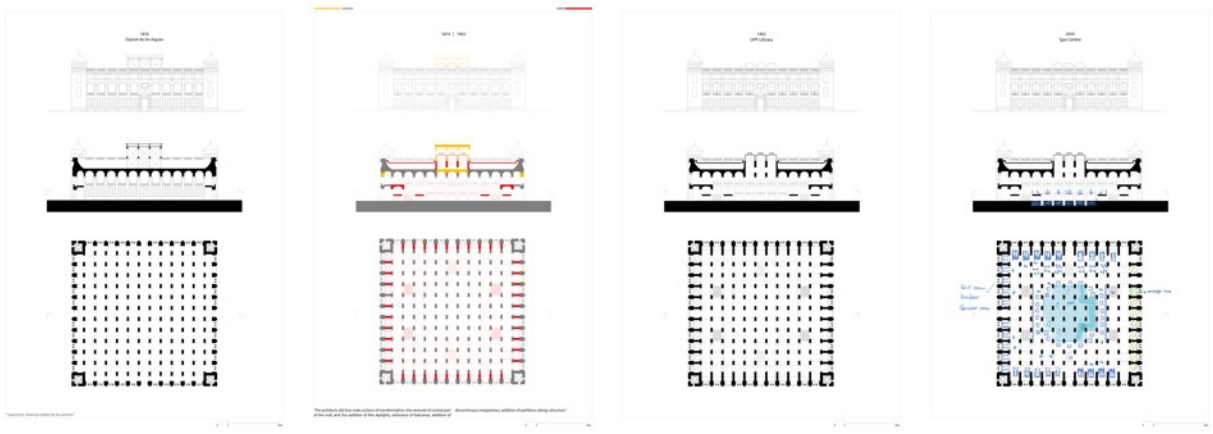


Figure 5: UPF Library (1874–1992/2050) in Barcelona (Spain). In 1992, the architects Luis Clotet and Ignacio Paricio Ansuategui transformed the former water reservoir Diposit de les Aigues into a modern university library. The graphic analysis of the transformation was followed by its expansion into a spa centre, designed by students Ala Talebian and Takumi Kondo, as a speculative step towards a possible 2050 conversion perspective. This discussion occurred during the academic seminar "Affordances of Architectural Typology" held by G. Postiglione, F. Serrazanetti, and M. Gold at the Technical University of Berlin in November 2023. Source: (Ala Talebian and Takumi Kondo in Architectural Affordances 2024)

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Making the Global Local: Designing and Building a Mobile Studio to Research the Impact of Industry, Globalization, and Climate Change on Coastal Communities and Ecosystems

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ABSTRACT: This paper proposes a radical, multi-phase approach to architecture studio education that combines design-build, expeditionary learning, and analysis-based design research to embed students in the mobile study of the shipping industry, globalization, climate change, and their impacts on coastal communities and ecosystems. The modern shipping industry is the backbone of international trade, accounting for more than eighty percent of world trade, and its impact on the environment, coastal communities, and culture in general has become increasingly problematic. The model presented here proposes a series of interconnected courses, including design-build studios, history theory seminars, and research methodologies classes to allow students to form a comprehensive understanding of the core phenomenon while utilizing research and architectural production as a mode of inquiry. In the first phase begun in spring of 2023, students will design and build a mobile studio housed within a modified shipping container, sited temporarily on campus but designed to be periodically transported aboard an ocean-going cargo container ship. During concurrent and subsequent theory courses, students will establish research agendas focusing on links between the shipping industry and climate change, cultural globalization, and the economy while concentrating on the transformative effects it has on coastal communities and the environment. Students will engage in gathering data, mapping, marking, and making while searching for the intersection between architecture and the impacts of modern global trade on the world. The following paper includes a historical and contemporary analysis of the core issues, an assessment of the first stages of phase one begun in spring 2023 and makes a case for the value of design-build, expeditionary education, and the importance of travel, not just in learning, but in learning to employ architectural production to examine in-situ the most critical issues currently facing society and the environment.

KEYWORDS: design build, expeditionary learning, sustainability

INTRODUCTION

On March 23 2021, the cargo container ship Ever Given veered off course in a sandstorm and lodged itself into the side of the Suez Canal, immediately halting numerous vessels on either side and, over the course of the next six days, blocking the way of more than four hundred other ships. While the total social, economic, and environmental impact of the event is still being calculated and will likely cause ripples for years to come, initial estimates of the economic losses were over fifty billion dollars. Almost ninety percent of all global trade is transported by ship and up to twelve percent of that moves through the Suez Canal. The accident affected nearly every industry from pharmaceuticals and insurance to construction, involved every kind of product from dinner forks to doorknobs, and disrupted the global supply chain to become one of the key factors of rising inflation. The event forced companies to ship around Africa, threatened a bottleneck in the Panama Canal, and halted major world development strategies, such as China's Belt and Road Initiative. With investments in more than seventy countries connecting China with Europe and Scandinavia, the initiative is heavily reliant on shipping imports and exports through the Suez and acts as a modern silk road (Lee and Wong 2021).

The accident occurred at the height of the Coronavirus pandemic that found much of the population of the planet in lockdown, many isolated with their own travel severely restricted and perhaps more dependent than ever on the shipping industry. It was, as one article put it, an event that "broke the world." And while much of the media was commiserating with the Ever Given's twenty-four crew members being equally stranded, that same article went on to describe the crew's conditions as routine. While they waited, it was life as usual performing their regular training, tasks, and drills with all the usual amenities available at the end of the day, including access to counseling and wireless internet (Christian 2021). While reading this, two details stood out. First, that the number of crew members was only slightly greater than that of a typical architecture design studio and, second, that although the Ever Given itself was stuck, the crew were not. They were far from being stranded in the middle of nowhere and, for all intents and purposes, they were home.

Motivated by these realizations, a radical approach combining experiential, transformational, and expeditionary learning was developed to lead students into unknown territory to study the most critical issues facing society where they happen. Unlike most study abroad programs in which students either move from place to place or live in one location for the duration of study, this new tactic will provide students with a floating home, like the crew of the Ever Given, allowing them to remain localized while the world comes to them. The proposal includes an analysis of the

impact of the shipping industry and climate change on coastal communities and ecosystems, makes a case for travel and experiential learning as a key method of developing students as global citizens, and presents the outcomes of the first phase of the project, the design and construction of a modified shipping container into a mobile design studio. Like the Outward Bound model, the project intends to engage students in

> a complete reorganization of time, space, and relationships among persons, across disciplines, between persons and learning technology, and between the school and community" (Campbell et al. 2012) to provide a total educational experience.

1.0 MISTER GO

Civilization is transportation (Kipling 1912). The earliest societies were established and developed by trade and commerce, through the exchange of not only goods and raw materials, but of ideas and culture. At the heart of this exchange is water. Ancient communities, isolated from each other by natural barriers, turned to rivers and seas to find links to world beyond. Over the centuries, this seafaring system has grown as a common, global interest in which all countries now cooperate as one, interconnected economic organism (Fayle 1933). The modern shipping industry is the backbone of international trade, accounting for more than 80% of world trade, and its impact on the environment, coastal communities, and culture in general has become increasingly problematic. As the shipping industry is forecasted to grow more than 130% by 2050, the future of global trade is the future of civilization (Kalouptsidi 2021). Unfortunately, this association means that, despite recent efforts to reverse climate change, our ability to shape a sustainable future will become ever more difficult.



Figure 1: The House of Dance and Feathers, New Orleans. Source: (Author 2006)

Although it can be argued that modern shipping has improved the quality of everyday life for the average person, the cumulative number of ways that the ships alone adversely affect the environment is staggering and has devastating long term consequences. From grey, bilge, and ballast water and other kinds of liquid pollutants like industrial cleaning solutions and sewage, to solid waste, refrigerants, antifouling paints often containing chemical compounds like chromium, to the global mesh of destructive noise and the ocean-wide conveyer belt for stowaway invasive species, a single ship can do a tremendous amount of damage to marine ecosystems, wildlife, and the fishing industry in an average thirty-year lifecycle (Andersson et al. 2016). Shipping accounts for more than 2.4 percent of total global noxious emissions which, by some estimates account for some seven million premature deaths annually, meaning the industry is responsible for more than one hundred and forty thousand deaths, each year, through emissions alone (Hasanspahić 2021).

Like the Suez Canal, shipping industry infrastructure including ports, canals, and building and scrap yards are even more destructive and, in many cases, for much longer periods of time. At least in one case, the Mississippi River Gulf Outlet, the damage was exponentially greater. Initially proposed as an emergency outlet from the Mississippi

River east of New Orleans in the interest of general commerce and national defense, constructed for over $580 million dollars and opened in 1965, the MRGO was “straight as a gun barrel” and, as critics pointed out, would serve as an inlet rather than an outlet. Coastal Louisiana wetlands populated by dense cypress forests that historically resisted storm surges from hurricanes were decimated by the MRGO, initially four hundred meters wide but, due to decades of erosion, over half a mile wide by 2005 (Freudenburg et al. 2009). In August of that year, category five Hurricane Katrina slammed into the coast of Louisiana and, acting like a straw, water surged through the MRGO and straight into the Industrial Canal at the heart of New Orleans’ Lower Ninth Ward. The resulting devastation cost an estimated $110 billion dollars, destroyed nearly 300,000 homes, and killed almost two thousand people. Although initially public perception was that the hurricane had caused the damage, it became clear over time that the disaster was manmade (Dyess 2013). The Mississippi River Gulf Outlet had become a city killer.

When working with students from Kansas State University and schools around the country to rebuild the House of Dance and Feathers Mardi Gras Indian Museum a year later, understanding the relationship of industry, the coastal ecosystem, and the levees to the Ninth Ward community was invaluable (Allweil 2007). It informed how we approached details, materiality, and building systems but, more importantly, helped us to build bonds, grow trust, and to better understand the residents of the Ninth Ward and how the industrial landscape had impacted and upended their lives. At a neutral ground barbeque that summer we got a powerful insight from one resident of the Ninth Ward, Demetrius Alexander, who said, “you can’t blame God for what the government did,” showing that the larger political, economic, and environmental systems in play were not lost on the people on the ground. It was an understanding that you are not likely get from a book or an academic paper; you have to be there.

2.0 OUTWARD BOUND

Travel has played a central role in most of my projects and my life. Constantly on the move since birth and having lived in many places for no more than a few months to a year, I am a nomad. Not like one of Thesinger’s traditional Bedouin (Thesinger 1959), but a *new* nomad defined by rootlessness, global hypermobility, and an ability to adapt to new ways of seeing and judging the world (D'Andrea 2006). Much of my work revolves around the same themes of community, place, memory, and disappearance. Captivated by loss, whether to space or time, I find myself perpetually in-between. *Ghostlands*, a set of design build architecture studios conducted between 2011 and 2013 addressing dead and dying towns in central Iowa, was firmly situated within this in-between (Rhodes 2017).



Figure 2: Ghostlands Studio, Mackey, Iowa. Source: (James Spiller 2014)

Only an eight-week summer design build studio, the first two weeks of *Ghostlands* was dedicated to travel, a six-thousand-mile expedition across the American west through national parks and abandonments. Inspired by the principles of Outward Bound, two of which are *The Natural World* and *The Having of Wonderful Ideas* (Campbell et al, 2012), the journey was designed to expose students to the fact that issues you face at home are faced by people everywhere, allowing them to form connections between disparate people and places across an unfolding

landscape. It also provided them with the space and time to design ways to take what they learned and apply it back home. As one student put it,

> I think the most important thing I've learned is there is a reason that each place is special. I really didn't understand that before. People are here because they love the town and they want to do whatever they can to protect it. I think that kind of passion for a place is commendable. (Sauer 2012)

The formation of this kind of perspective is the foundation of becoming a "global citizen", characterized by an expanded world view of responsibility and belonging opposed to ignorance and intolerance. Despite recent anti-globalist rhetoric, the US remains heavily invested in student study abroad, demonstrated by the 2005 House of Representatives bipartisan Lincoln Committee report leading to the Paul Simon Study Abroad Foundation Act which aimed to increase the number of students studying abroad over the next decade to one million, an increase of 400%. The key drivers of the legislation were both national security and global competency, with a desire to develop a global citizenry to ensure that the US remain competitive in an increasingly global marketplace and able to respond effectively to environmental concerns such as resource scarcity and climate change (Tarrant et al. 2014). A growing body of empirical evidence, especially concerning sustainability and global citizenship, suggests that if educational travel is used to develop global citizens, the focus should be on environmental issues, although there is evidence to show that merely participating in study abroad develops a global ethos (Tarrant et al. 2011). A series of studies demonstrated that, within a rigorous pedagogical framework rooted in bigger questions of social and environmental justice, study abroad programs can lead to shifts in students "values, beliefs, behaviors, skills, insights, and particularly one's overall disposition to critical and self-reflection" (Stoner et al. 2014). In other words, the journey is the thing.

3.0 NEONOMADS

In the spring of 2022, students began designing and building a modified shipping container to be used as a mobile design studio and lab able to be transported on an ocean-going cargo container vessel. Aboard ship, the intention is that the modified container will be utilized as a classroom, workshop, and exhibition space in support of an expeditionary applied research and theory course, slated for the spring of 2025. The course combines expeditionary learning, applied research methodologies, and critical thinking with the analysis of forms of globalization, such as commerce, transportation, and communication. The course will focus on links between the shipping industry, globalization, ocean ecology, climate change and the transformative effects these have on coastal communities, while designing sensitive architectural propositions in response guided by the United Nations Conference of the Parties (COP) and Sustainable Development Goals (UN DESA 2023).



Figure 3: Installing entry unit. Neonomads, United Arab Emirates. Source: (Author 2023)

The container is being designed for a minimum twenty-five-year lifecycle, with system parameters developed in consideration of deployment, constructability, and operation, leading to a short list of fundamental components. The building will be programmatically and environmentally sustainable, utilizing reuse, repurposing, and recycling

strategies when possible and implementing innovative materials, systems, and technology selected for their durability and resistance to the unique climatic conditions of the Arabian desert and the open ocean. Special attention will be paid to ensuring the structural integrity and seaworthiness of the container for future transport.



Figure 4: Fabricating entry ramp. Neonomads, United Arab Emirates. Source: (Author 2023)

The project is phased over several semesters to slow down, to achieve more depth in each aspect of the design and fabrication process, and to take advantage of multiple funding. This also has the advantage of engaging more students and developing a legacy project, in which the work is passed down from one cohort to the next over time, increasing buy-in from students and administration. the phases obviously have some overlap but are designed to be distinct enough so that each batch is simultaneously designing and constructing something new, tying into the last phase and finishing up leftover details, and anticipating what will come next while providing flexibility and freedom for the next cohort. Although the first studio groups will likely not be present for the ocean-going journey, the ramifications of this eventuality are forefront in student design decision making from the start. The connected process encourages altruism as students, who may not benefit directly from the travel experience, are dedicated to ensuring its future success (Bartels 2013).

While on board during travel, students will be lodged in crew quarters and have access to dining and recreational facilities, while operating out of the container studio and lab. Moving from one port to the next in Southeast Asia and MENA regions, selected for their unique environmental and cultural conditions relative to a research agenda, they will spend their time on board recording and documenting the natural and built environment, gathering data, mapping, marking, and making while searching for the intersection between architecture and the impact of modern global trade on the world. What they make along the way will evolve out of research, discourse, and experience. The course will disseminate its research and design outcomes, including the possibility of full-scale built work, through publication, installation, and exhibition.

CONCLUSION

Assessing the outcomes an unfinished project can be challenging, especially one at the beginning of an ambitious design build phase that promises to culminate in such a radical study abroad experience as to be, to some, a pipedream and, to others, wholly unnecessary. During the *Ghostlands* studios, we used travel to prepare for the design build phase, which was the point of the course, but in the case of the current project, educational travel to develop global citizenship is the ultimate aim. Building first has transformed what was previously an overwhelming and primarily conceptual worldwide set of issues and made it real by bringing it to our doorstep. A microcosm of the larger problem, the container is packaged appropriately in terms of scope and scale, while remaining interconnected with all the larger themes surrounding industrialization and the environment. Fully funded and two semesters into the design and fabrication of a modified shipping container mobile classroom, it is clear that the program and

institution remain invested in the larger idea and, like most design build projects, the learning so far has been immense.



Figure 5: Fabricating windows and doors. Neonomads, United Arab Emirates. Source: (Author 2023)

For many of the students, this was their first building experience, and it was comprehensive. They were introduced to and, in many cases, became experts in new methods of metal fabrication, including MIG and TIG welding, CNC milling, and the design and construction of complex jigs used to reproduce multiple but identical parts and assemblies more efficiently. We spent the spring of 2023 fabricating windows and doors for an ambitious envelope system and the following fall making most of them again, learning a critical lesson that windows are not doors, and doors are not windows. Due to time constraints but also in preparation for practice, students worked closely with outside fabricators, while designing and having machined a variety of component parts and details from custom hinges and doorhandles to hardware, fasteners, and lighting fixtures. Working with subcontractors and consultants in the construction, solar energy, and transport modification industries, students generated shop and construction drawings, coordinated, and managed every aspect of the construction process, to this point. They researched industry standards while innovating new systems, including an integrated, demountable cladding system using strut channels to house steel frames that contain both the exterior insulation system and the solar panel array. And they discovered new materials, like expanded cork block, a wonder material known for its sustainability and insulative properties, whose origins date back to the last nineteenth century, supplanted by petrochemical products after World War One, and little-known today. Students' assumptions that shipping containers are clear, simple, and standard were challenged through a complicated and near endlessly iterative design process that found that no two containers are alike, at least in our experience. And finally, their preconceptions of a project about water and an industry of movement meant to be fast, fluid, and constructed with high degrees of tolerance were overcome by a building process that has been heavy, slow, hard, and unforgiving.

My own education surrounding this project began much further back. As a boy, I watched a re-run of David Lean's *Lawrence of Arabia* on television, and I was awestruck by a scene that would stay with me. Just over two hours into the film when Lawrence and his friend, Farraj, are wandering through the Sinai desert and are near death, they are stunned by the top of a cargo ship floating through the dunes and sounding its horn. They had found the Suez Canal and civilization and were saved. At the time, the scene stirred a wanderlust in me, and I have wanted to be on that ship ever since. In 1962, when the film was released, it was unusually controversial for its time and, over the ensuing years, there has been much debate about its attitude towards imperialism and colonialism. Although many scholars have praised the film for its anti-colonialist stance (Dawson 1996), a more sensitive look through a current lens reveals that many problematic themes remain relative to cultural appropriation, masculinity and gender identity, and the myth of the white savior. Forty years after seeing the film and after more than a decade living in the Arab world, I realized before starting this project that I would have to check my romantic childhood impressions and cultural biases and carefully reconsider them. Like the project, that process is ongoing.



Figure 6: Craning container onto site. Neonomads, United Arab Emirates. Source: (Author 2023)

Whether we ultimately take the trip or not, the building project is an educational end in itself. More importantly, as a symbol of the larger idea its bold, in many ways inspirational, and begging to culminate aboard a ship on the open ocean. Like the Mardi Gras Indians of New Orleans who hang feather samples from their front porches each year, it says we are coming. One day soon, we will.

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Informing Life Cycle Assessments Through Design for Disassembly

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ABSTRACT: What determines the lifespan of building materials? This question can be approached in numerous ways. In this article, we work from the assumption that the least erroneous answer is: the future.
Design for disassembly (DfD) is a way to mitigate the uncertainties of dealing with the future of construction and as a way to relinquish material lifespan from construction lifespan. (Crowther, 1999) DfD is an instrumental part of developing circular economy in architecture where lifespan of materials cannot be defined by the typology or construction type as it facilitates disassembly on various levels of a building. DfD is a strategy often referred to in literature as prompting longer lifespans of materials through reuse and recycling thereby potentially both reducing the need for virgin material resources in construction and prolonging the use of a resource. Simultaneously DfD prompts an architectural understanding of buildings as changeable artifacts, as open-ended entities. By juxtaposing the principles of DfD and LCA, this article forms a critique of the understanding of lifespan represented in conventional LCA. To contextualize this inquiry, two examples of DfD in contemporary construction are analysed, where the specific conditions for disassembly in the façade systems are laid out. The examples are two hybrid building systems in the current Danish building industry which show fundamentally different approaches to disassembly. The two examples and all data from chapter 5 in this article is based on case studies carried out by one of the authors of this article, as a part of an ongoing Ph.D. project anticipating completion in the spring of 2024. The resulting discussion is concerned with the possibility of informing the conventional LCA paradigm by imposing on it, notions of the unpredictable nature of the future, of lifespans, of end-of-life and reuse scenarios, with which DfD is occupied.

KEYWORDS: Design for disassembly, life cycle assessment, circular building principles, facade design

1.0 INTRODUCTION – BUILDING FOR AN UNKNOWN FUTURE

The Brundtland definition of sustainability exhibits an inherent understanding of sustainability as an ideas closely interwoven with a notion of an unknown future, which is very clearly stated in the extensively used quote from the Brundtland report (Keeble1988):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

With this in consideration, the practical and philosophical implications of choosing and planning for a specific future becomes apparently problematic. We know that our actions must not compromise future generations but what does the future need and how do we get there? Many environmental impacts are tied not just to what we do (build) today but equally to how the built environment can adapt or change with the unforeseeable demands of the future. The total environmental impact of buildings depends on past and present decisions and on the multitude of yet unknown variables of the future. As buildings potentially have very long lives, we would have to be able to look far into the future to be accurate in our assessments. This is the apparent embedded weakness in LCA and this article investigates how the unknown future can be addressed otherwise: through design for disassembly.

Product stage			Construction installation stage		Use stage							End of life stage				Beyond the system boundaries
Raw materials	Transport	Manufacturing	Transport	Construction installation stage	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 1: LCA stages that are included in the calculation according to Danish Building Code. Stage D is not included in buildings that are more than 1000 square meters. Source: (Diagram by Pelle Munch Petersen 2019)

Life Cycle Assessment (LCA) is a method for assessing the environmental impacts of a material, product or a service by factoring in the full lifespan from cradle to grave. LCA (as methodologically defined in the Danish building code) work by both establishing the actual and measurable environmental impacts tied to the production of the

materials in a construction (Stage A1-A3: Product stage) and by assuming future impacts in the later stages of the materials life (Stage B Use stage, Stage C End-of-life)(Hansen and Hansen 2018). However, the longer the life of a given material, the more variables there are for future scenarios and therefore the more speculative the assessment becomes.

Therefore, we look at how DfD can be used to construct in a way that allows for many different future scenarios to unfold and discuss what consequences DfD can have on LCA DfD allows for better scenarios regarding maintenance, selective non-destructive demolition partially or for the building as a whole. It is a strategy often referred to in literature as prompting longer lifespans of materials through reuse and recycling thereby potentially reducing the need for virgin material resources in construction. Simultaneously DfD prompts an architectural understanding of buildings as changeable artifacts. Designing a building for disassembly is about anticipating the future unknown and possible physical changes of a building. DfD can be incorporated as a design strategy for the ease of taking a building apart instead of destructive demolishing at EOL.

2.0 RESEARCH QUESTION AND METHOD

What is the relation between LCA and DfD regarding lifespan of materials? How does their respective governing logic showcase different approaches to the understanding of the potential life of building materials?
To contextualise this inquiry, first the governing logic of LCA in construction is analysed and secondly two examples of DfD in contemporary construction are pinpointed, where the specific conditions for disassembly in the building systems are laid out. The examples are two hybrid building systems in the current Danish building industry: WoodStock and LCT. The two examples show different approaches to the processes of assembly and disassembly of the building envelope, which are influential on the possibility of separating the lifespan of buildings from the lifespan of its materials. Lastly the two different takes on the future life of materials are discussed in relation to LCA.

3.0 PROBLEMATISATION OF THE CONCEPT OF LIFESPAN IN LCA

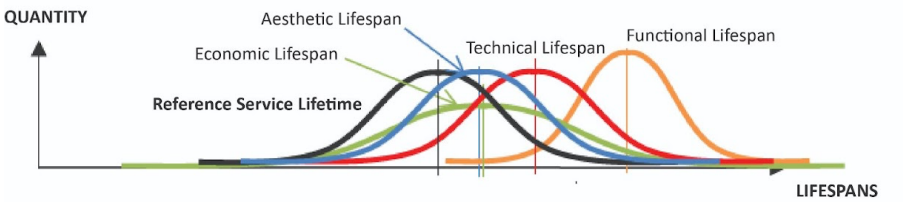


Figure 2: Different competing lifespans. Source: (Original diagram by Aagaard et al., translated by Pelle Munch Petersen 2019)

3.1 The role of lifespans in life cycle assessments

The lifespan of materials in LCA is commonly defined by recommendations that are compromises between different hypothetical competing lifetimes. These lifetimes are referred to as (Aagaard et al., 2013):

- Technical lifespan
- Functional lifespan
- Economical lifespan
- Aesthetic lifespan

The resulting lifespan of any given material is in reality defined by a complex interplay of many potential lifespans. The defining lifespan is the shortest of the possible lifespans. In construction, building materials work in connection with other materials and therefore the lifespans of all materials in a given construction should be investigated collectively. Especially in cases where materials are connected in non-reversible ways. Here the material with the shortest lifespan will be the defining lifespan.
A lifespan that is not addressed adequately is *political lifespan* as political motivated demolition is common but impossible to predict. The politically motivated demolition can be motivated by a wish to mitigate ghettos, make way for new development etc. As such, to say anything about the future life of buildings and the lifespan of material is difficult. In many it is defined by other factors than the material itself. Rather the joining, the context, political climate and more define the lifespan.

3.2 Lack of general knowledge on the lifespans of buildings

In a Danish context the research and documentation of building lifetime material use is very limited. Energy use of buildings is calculated and measured in all construction as it represents a running cost. As such operational energy is accounted for but the embedded impacts of materials are so far not considered accurately. The only register in Denmark that monitors the material use and life of buildings is called 'Building and Dwelling Register' [BBR] (Bygnings- *og* boligregister*, BBR*, n.d.).

However this register is flawed, and inconsistent as it is the owner's responsibility to update and register changes in construction, technology, and use. Doing this requires technical knowhow and can be difficult for common building owners. Furthermore, not all owners are aware of their responsibility to update and maintain the register.

Consequently, looking into the Danish situation of building life and material lifetime there is not enough data. The BBR is incomplete as registration of typical upgrades and maintenance are not required. Therefore, it is extremely difficult to predict the life of a building material based on retrospective analysis of building data. When doing so anyway the calculation becomes quite hypothetical and LCA must be considered hypothetical if not unrealistic.

3.3 What determines the lifespan and end-of-life of building materials?

It is virtually impossible to predict with precision the lifetime impacts and *End of Life (EoL) scenario* of a specific building or building material. The shorter the technical lifespan a material has - the higher the accuracy of the assessed lifetime impacts - as it can be done with some empirical precision. If we for instance know that the sealant/resin in the spacer in a three-layered-glazed window glass will last no more than 25 years - then we can know with some accuracy that it will not last longer than that. Meanwhile, only very few materials and components in construction have such short technical lifespan. Often the material with the shortest lifespan will determine the "Reference Service Lifespan" (RSL) (the estimated lifespan of a material). For instance, the economical lifespan will be the defining parameter, if it is cheaper to discard the material and buy new - or discard the building and build a new one. And, if the nail with which a panel is mounted lasts a shorter time than the panel, the lifespan of the panel might be defined by the nail. As such the construction as a whole also defines the lifespan of a material.

3.4 A fixed future or an open-ended future?

LCA does not necessarily take into account the possible implications of the possibility to reuse or recycle materials after End-of-life. LCA does not promote a Circular Economy for this reason. This coincides with the intellectual conflict between the architectural strategy of DfD and the logic of LCA. As will be showcased later in this article the primary aim of DfD is to facilitate reuse and recycling and thereby prolonging lifespans of building materials and buildings. During the last year the Danish building code has defined the environmental loads of reused materials (in stage A) in two completely opposite ways showing how difficult the notion of reuse is: First reused materials should be calculated with the full impact as a new produced material and from 2024 the same reused material has zero loads in the LCA calculation (Bolig og planstyrelsen, n.d.). None of which can be an accurate description as reuse represents environmental loads but far less than new production.

Secondly EOL scenarios are based on what happens to materials today when they are discarded. That means that all development is put to a hold in a fixed understanding of the future that only reflects practice today. The only exception to this is the operational energy (stage B6) that can be calculated with a *dynamic energy mix.* Here LCA is anticipating the development in energy-mix based on development so far and the politically decided future for Danish energy production.

4.0 'DESIGN FOR DISASSEMBLY' AS A STRATEGY FOR PROLONGING LIFESPANS

Acknowledging that the future is unknown leads to questioning the hypothetical and linear and fixed nature of LCA scenarios possible in phase B and C. Architectural design can be a way of dealing with the uncertainties of the future, by designing for many possible futures instead of one specific. Design for Disassembly as an architectural design strategy focuses on allowing the disassembly of buildings or parts of buildings. DfD facilitates structural and spatial flexibility, where physical changes can be done in a non-destructive way and makes way for understanding buildings and structures as changeable artifacts. DfD was conceptualized in the product industry in the 1990's, has slowly migrated into architectural theory and is by now quite well described in literature as a technical strategy. (Sassi 2002) (Brand 1995) (Addis & Schouten 2004) (Nordby 2009) (Munch-Petersen 2019) However, it is still not a common working concept within the building industry in Denmark. DfD as a strategic position towards construction originated in the product industry and is slowly being incorporated in the building industry within a larger paradigm focusing on design for sustainability, which is one of the most complex and ambitious design concepts, having sustainability as the end objective (Kauschen 2014). DfD is found to be a sub-strategy to several of these more complex design strategies, which makes it interesting to explore. (Guy et al. 2008)

Designing buildings or parts of buildings for disassembly facilitates reuse and recycling on material, element, component and building level, by relinquishing material lifespan from construction lifespan (and the other way around) (Crowther, 1999). As such DfD arguably challenges the temporal aspects of the LCA model – more precisely the fixed notions of lifespans and EOL-scenarios – by purposefully facilitating reuse and recycling on various levels. Reuse and recycling prolong the lifespan of that which is reused or recycled, thereby complicating the assessment of its lifecycle. DfD works in favour of a circular material economy, whereas the LCA model favours a linear material economy for making precise assessments as the assessments depend on the given EOL-scenario.

However, DfD and LCA are not to be understood as opposition ideas. They converge on the topic of environmental impacts. Where DfD enables a prolonging of the lifespan of building components and their materials by reuse and recycling, which in turn can lower negative environmental impacts, LCA is used to assess environmental impacts from cradle to grave of a building or component. This is where DfD challenges conventional models of LCA; by making possible (low impact) EOL-scenarios and increasing the potentials of LCA stage D ('Benefits and loads beyond system boundary') usually describing potentials of reuse, recovery, and recycling. This article presents two different cases of DfD in façade construction to investigate DfD in practice and how this relates to LCA stage C and D.

5.0 ANALYSIS OF DFD IN TWO EXAMPLES OF BUILDING SYSTEMS

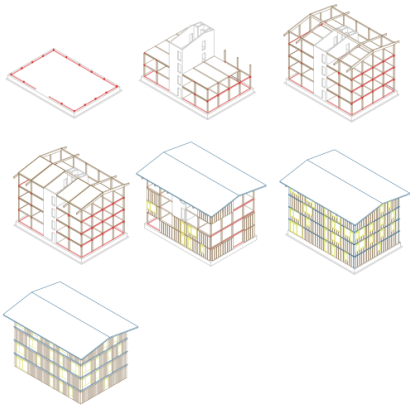
The concept of disassembly is concrete and tangible; that which is assembled should be able to be disassembled. Assembly details and choice of materials for a building can facilitate - or stand in the way of easy disassembly. However, it is still not a common working concept within the building industry in Denmark.

In this chapter two examples of DfD in contemporary construction in Denmark are pinpointed, where the specific conditions for disassembly of the façade systems are laid out. Both examples are multistorey hybrid building systems for residential purposes. All information and data in this chapter is based on case studies carried out by one of the authors, as a part of a Ph.D. dissertation anticipating completion in the spring of 2024.

The two building systems, WoodStock by the architectural office Tegnestuen Vandkunsten & LifeCycle Tower by CREE GmbH, are examples of two different approaches to DfD in the current Danish building industry. The building systems in question are both hybrid constructions, where concrete, steel and wooden elements make up the structural - load bearing - parts of the buildings. Hybrid construction as a term covers basically the structural part of a building which is composed of more than one type of building material. The DfD strategy presented accounts only for the facades, as they are non-loadbearing and as such are considered having great potential for disassembly. By a qualitative analysis of how possible future disassembly of the façade in the two cases would be done, the static and dynamic conditions of the two building systems becomes evident along with their future circular potentials. As the focus of the analysis is solely on the facades, this article will not consider the parts of the two building systems which apparently present great challenges for disassembly. Examples of these parts are the reinforced concrete structures, the composite wooden-concrete floor slabs, and the concrete foundation. As the objective of this article is to analyse the practical and concrete disassembly of façade systems through the construction drawings of connections, to discuss the role of facilitating reuse and repurposing in the LCA model, the inquiry will not go into the objective of the disassembly or how the dismantled part would be reused or repurposed. Whether the disassembly happens because of the need for modernizing the building or other scenarios, the focus of this article is specifically on the assembly type and way of disassembly of the described façade system.

So, in the following we investigate two different approaches to DfD as a strategy for construction facilitating potential change according to new demands by disassembly for reuse or recycling of materials.





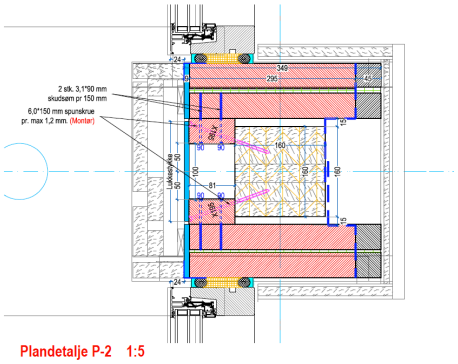


Figure 3, 4 and 5: Fig.3 Photograph showing dwellings on Lisbjerg Bakke. Source: (Line Kjær Frederiksen 2024) **Fig.4:** Illustration of some of the steps in the building process as accounted for in the educational handbook *Anvendt Byggeteknik i Dansk Arkitektur.* Source: (Leimand et al. 2018). **Fig.5:** Construction detail that shows the paper doll concept of assembly and disassembly. Source: (Tegnestuen Vandkunsten A/S 2017)

5.1 WoodStock - Tegnestuen Vandkunsten A/S

The hybrid building system WoodStock is developed by the Danish architectural firm, Tegnestuen Vandkunsten in collaboration with MOE Consulting Engineers and carried out in the residential housing Lisbjerg Bakke in Aarhus, Denmark. Lisbjerg Bakke consists of six multi-story dwellings of 3 to 4 floors with a total of 40 housing units. The project was finished in 2018 and was the first Danish multi-story public housing using load-bearing wooden structures in contemporary construction industry. The project team used LCA's to assess global warming potential of the building materials' environmental impact as a part of their design process, as the client opted to get a DGNB-certification. The buildings were awarded DGNB Gold in 2020.

5.2 Building process

The steps show the load bearing structure consisting of cast concrete foundation and concrete element staircase, the glulam post and beam structure is built around the staircase one floor at a time. As a gesture of thinking ahead, the steel bracket connections in the post and beam structure are prepared for mounting balconies, if a future need arises. The beams shown in red are steel beams, which are chosen with the intent of keeping a low construction height for the floor slabs. The floor slabs are prefabricated cross laminated timber elements, which are then added

a layer of 9 cm concrete cast on-site, one floor at a time, to give a composite effect for the slabs to comply with requirements for acoustics, fire, and structural stability. Followingly, the glulam roof purlin and trusses are mounted.

The roof structure is finished by mounting prefab insulated elements between the trusses and is covered with metal sheeting. A few places in the facade, CLT-elements are mounted in between two glulam columns for structural stability. Prefab insulated facade elements are mounted on the glulam columns and on the concrete staircase. This is done starting on the top floor working down. The elements vary in design (one or two windows and/or a door, or no openings at all) depending on placement in the facade.
The horizontal zinc flashings are mounted for each floor, preventing water from penetrating the facade and lastly the facade cladding of spruce boards is mounted.
In the construction process only, lifts were used and no scaffolding as there was no need for a covered construction site.

5.3 Disassembly process

Focusing on the building envelope façade, the disassembly process of the WoodStock building system is analogous to the concept of a paper doll; a basic figure dressed or clad in a way where the cladding can be removed one layer at a time. From the construction detail above it is visible how the disassembly process would be in case of future needs for changes. For example, if balconies were to be mounted, it would be necessary to access the steel brackets in which the glulam columns are fixed. This would be done manually by unscrewing the spruce board cladding, then unscrewing the substructure of wooden slats, then removing the small strip of fiber cement and mineral insulation, which is closing the gap between the façade elements and the columns. At this point, the steel brackets and bolts are accessible for mounting balconies. At this point, the 6,0x150mm screws are accessible as well. The screws are accessible from the outside of the façade elements, which means that the entire façade element can be unscrewed from the columns and removed in one piece. Further disassembly of the façade elements would most likely happen off-site or on the ground at least.

This process of disassembly facilitates removal of several layers of the façade or entire façade elements without affecting the basic figure of the paper doll. The disassembly of the façade can be done independent of the building process. A kind of autonomous approach to disassembly becomes possible.

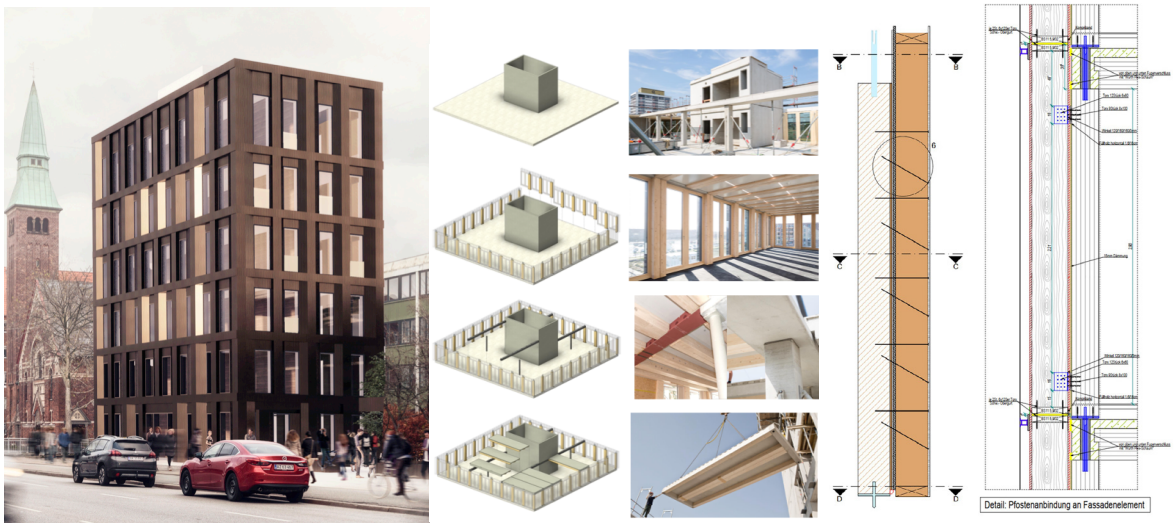


Figure 6, 7 and 8: Fig. 6 Visualisation of the student housing and café on Østerbrogade 190. Source (Vilhelm Lauritzen Architects, CREE Building 2018) **Fig. 7:** Detail that shows the montage of the façade elements, glulam beams and hybrid floor slabs. Source: (CREE Building 2018) **Fig. 8:** Two vertical sections construction drawings (to the left); the first showing the connection type using long screws. Source: (CREE Building 2018)

5.4 LifeCycle Tower - CREE GmbH

LCT is a hybrid building system property of CREE (an abbreviation of Creative Resource & Energy Efficiency) which was born from the Austrian construction company, Rhomberg Group. Several multi story buildings have been built using the LCT hybrid building system. The first building was LCT One in Dornbirn by Herman Kaufmann Architekten from 2012, is an 8-storey building. Most recently in Copenhagen, Denmark, a 6-storey residential building with a café on ground floor is in the making by a project team consisting of CREE Denmark (licensed CREE partner), Vilhelm Lauritzen Architects, and MOE Consulting Engineers. The building on Østerbrogade 190 has yet to be realized. Nonetheless it is interesting as a case given the high degree of information which is available on the building system.

The CREE building system constitutes the superstructure and the building envelope. The design and choice of materials for the rest of the building is up to the project design team. With regards to working with LCA's, CREE does preliminary LCA's to help early design decision making and therefore mainly look at the LCA stages of A1-A3, at times including A4 if known. Other than that, CREE uses LCA for comparing the building system against other more conventional constructions on a structure-to-structure level (Tim Steffinger, Elif Istanbulluoglu, email to author, June 22, 2022) Depending on parameters like design, location, footprint and more, the embodied carbon of a CREE

structure changes, which means that comparisons to e.g., conventional concrete or steel construction, needs to be done singularly on the specific constructions to be precise and useful.

5.5 Building process

As the CREE building system can adapt to specific needs, there are multiple solutions to the load bearing structure (glulam columns, hybrid ribbed slabs, a stiffening concrete core or wall panels and steel middle girders, where necessary). The following describes the most generic solutions and the design choices specific for Østerbrogade 190.The unitized superstructure relies on standardized industrial prefabrication. The building process of the LCT-system begins when the foundation is laid. Given the 6 stories of the planned building on Østerbrogade 190, the LCT structure is fixed to the concrete foundation. First the concrete element staircase is erected and then the deck is built around it, by assembling one floor at a time. Then prefabricated non-loadbearing façade elements and the load-bearing glulam columns are mounted as one element, by lifting it in place so that the bottom of the columns is fixed onto a round metal bar. This connection is then cast with a cement-based mortar. The prefabricated hybrid floor slabs (made of reinforced concrete cast together with glulam beams resulting in a composite effect) are then hoisted onto the metal rod on the top of the columns. With this procedure only cranes are needed, and an entire floor can be closed off in one day as described the CREE Planning Manual. The roof construction on Østerbrogade 190 is not specified, but it will be a flat roof.

There is no defined standard for the mounting of the façade cladding on the CREE structure, but it can be done both on- or off-site. Preferably off-site as a part of the prefabrication of the facade elements, as it reduces the working hours on-site. Either way, the substructure of the cladding is affixed to the studs of the timber framework of the facade elements using long screws. On Østerbrogade 190 the cladding is not yet chosen, but anodized aluminium is suggested.

As CREE does not themselves carry out any manufacturing, the company relies on local manufacturers to produce building components. The prefabrication process can be adjusted to fit the production line of the specific manufacturer, as the details can be altered in relation to special requirements of manufacturers. Most manufacturers use their standard production line for prefabricating the CREE facade elements, optionally adding a workstation for attaching the timber framed walls to the glulam columns.

5.6 Disassembly process

There are several solutions to multiple construction details in the LCT building system. With regards to the façade elements, two connections are possible. One is fixing the façade element to the column with long inclined and horizontal screws through the studs of the timber frame. The other solution, which is used in the first project with LTC, is using large steel brackets. It has not been possible to verify which method will be used at Østerbrogade 190, so for this analysis, the assembly with long screws is used as an example.

The timber frame facade element is assembled and insulated before it is fastened to the glulam beams with long screws through the timber frame studs. The element is closed off by screwing a fibre cement board into the timber frame, which means that you would have to remove the facade cladding, the substructure, and the fibre cement board before accessing the screws for unscrewing the element from the columns. Still, it would be necessary to cut the fibre cement and OSB boards to remove the element horizontally, because of the groove and tongue-like interlocking of the top and bottom of the elements. This is the case for both types of connections (brackets and screws) of the elements to the columns.

In both examples, the assembly process is like that of LEGO, where the prefab elements + columns interlock vertically. The disassembly of the building would therefore have to begin from the top by demounting first the roof and then one floor at the time, by first separating stiff connections and secondly lifting elements. Like LEGO, you cannot take out a LEGO block in the middle of a structure – you must take the LEGO structure apart top-down. As such, the process of disassembly would be the reversed version of the assembly process.

6.0 DISCUSSION; HOW CAN DFD INFORM THE NOTION OF LIFESPAN IN LCA

6.1 The two building systems

The two cases: two seemingly similar hybrid building systems, are examples of different ways of working with DfD. Removal of the façade cladding is in both cases possible to do at all times of the building's life. The 'LEGO' concept found in CREE and the paper doll concept found in WoodStock points to two different perspectives on lifespans; With the paper doll concept of DfD, it is possible to separate the materials' lifespans from that of the building. With the LEGO concept this is not possible.

In the case of the LCT, the connection of the façade columns and floor slabs are not mechanical, and as there is a groove and tongue effect of the façade elements (which according to the building system preferably are mounted on the facades' columns and assembled as one element) when mounted on top of each other, one floor at a time, the façade elements will in effect become quite difficult to separate individually from the rest of the structure. This indicates that the disassembly of the individual façade elements will have to happen in a reverse linear sequence of assembly and thereby will require disassembly of the elements above a given façade element in order to remove it. Or instead, a disassembly causing slight destruction of materials where potential cutting is needed. However, if the disassembly of the structure is carried out in reverse order of assembly, the façade elements could be handled

in a non-destructive manner and potentially be reused as an element or undergo disassembly into its constituent materials.

A different scenario becomes evident in the case of WoodStock. Individual parts of the façade cladding can be unscrewed from the wooden strips, revealing where to unscrew the individual façade elements from the wooden structural façade columns. Individual façade elements can be disassembled from the structural framing without affecting the other façade elements.

Regarding potentials and disadvantages in both cases it is quite easy to change the façade cladding, which makes possible many future surface expressions. Regarding the disassembly of the façade elements from the load bearing structure, in the case of LCT the facade elements are not designed for disassembly from the load bearing structure, as is this case in WoodStock.

6.2 'LEGO' and or 'Paper doll' regarding LCA

The 'LEGO' and the 'Paper doll' showcase the potential in material reuse (by means of DfD) and open doors for many future scenarios and by doing so undermine the linear fixed logic of LCA and the premise of all stages except for stage A. Stage A is already done when the building is erected and as such it's impacts belong to the past. But the rest (stage B, C and D) has not happened yet and as such both systems showcase possibilities for different lives and for materials reuse that extends the life of the building, they are part of.
For experienced practitioners of LCA it is commonly understood that LCA is merely a scenario-based calculation tool and not a realistic prediction of what will happen. But as the tool promotes an understanding of predictability of construction lifespan, chances are that the benefits of DfD will never be employed by LCA practice as we cannot calculate the potential gains. The number of possible outcomes is simply too great.

How to best deal with the temporal aspects of construction? As established the consensus today, represented in LCA, is that the future is best dealt with through calculation of impacts now and over time regardless of the limitation this logic entails. In this article, we argue that this can lead to inaccurate assumptions of best practice. The future is unknown and therefore a different approach to impacts over time is necessary. DfD represents an approach where instead of insisting on fitting the unknown nature of the future into a quantitative normative calculation model (LCA) it transfers the problem into an array of design solutions that allows for many possible future scenarios. This challenges the foundation of the linear temporal understanding represented in common LCA. Making it possible that the technical lifespan of the material in fact becomes the RSL by separating the life of the material from the life of the building.

Stage D is commonly 'outside system boundary' and thus not part of an LCA-calculation. However, in both cases mentioned above a best practice and use of the systems will mean that the benefits of reuse should be able to be transferred from stage D to stage A of the next lifecycle (next building). This would mean that processes in stage C (C3 and C4) become redundant as well. This is especially the case when the technical lifespan is potentially longer than the functional, economical, aesthetical, and political.

We argue that very short-lived material impact (technical lifespan) should be considered in a stage B (use stage) as these materials might have to be changed periodically with new ones. But even more important it is to design short lived materials into composition in accordance with the 'Paper doll' mindset where it can be maintained easily in a non-destructive fashion. A full recalibration of the building envelope is possible, e.g bigger or smaller windows can be applied to accommodate different functional demands. It also makes partial refurbishment possible and thus allow for the building to retain its relevance over time. And if not, at least its materials can live on. The 'LEGO' approach is not as dynamic as the whole building has to be taken apart top-down. This way, in theory, the individual elements can be reused, but the building system does not allow for partial disassembly, which can hinder transformation and maintenance. As such, the most significant difference between the two examples is that the paper doll approach makes it possible to separate the lifespan of the facade elements from the lifespan of the building, which is not possible in the LEGO model.

CONCLUSION

The analysis of LCA showcases a fixed linear approach to time and building material lifespan. LCA deals with scenario-based approaches to the future that in some ways reflect status quo (EOLs) and thus hinders development, and in other ways bases the calculation on inadequate data based on an unknown and unsubstantiated past.

The future is difficult to predict and LCA exemplifies this well. But design does not have such limitations. Design can deal with many futures. As it becomes clear in the case studies design can ensure a separation of the building life and the material life.

In essence LCA and DfD complement each other well. The first is a normative calculation tool and the latter is a design method. LCA works well in establishing impact here and now (stage A) but lacks credibility in dealing with the future. DfD opens for many possible futures to take place and thus compensates for the lacks in LCA. Together LCA and DfD form a solid sustainable design approach.

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Performance Evaluation of Digitally Fabricated Perforated Screens Inspired by Mashrabiya in Hot and Humid Climate

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ABSTRACT: In response to the escalating energy costs associated with air conditioning, architects and researchers increasingly turn to passive cooling strategies, emphasizing effective heat reduction, shading, and natural ventilation. One possibility is to introduce elements from vernacular architecture around the world into different climates. This study is aiming to evaluate the performance of a traditional element from hot arid climates to hot-humid climates. The traditional Mashrabiya screens from the Arabic architecture used to mitigate high indoor temperatures while regulating sunlight and preventing glare. Four screens were prototyped with controlled perforation parameters, utilizing Rhinoceros 3D and Computer Numerical Control (CNC) technology. The screens were produced with varying perforation percentages and thicknesses. A testbed reflecting common U.S. construction techniques was constructed for assessment, incorporating indoor and outdoor sensors measuring temperature, air velocity, humidity, and light intensity. The methodology included controlled airflow laboratory testing and outdoor testing that lasted a minimum of 48 hours for each screen, alongside a control scenario without any screen. Air movement was generated for laboratory testing using Surfer software for multiple scenarios to understand the effect on the indoor air speed when using the different screens. The collected data revealed diverse performances among the screens. The screen with 30% perforation and a 10 cm thickness demonstrated the best performance, effectively moderating indoor temperature and distributing light. Screens with the very high perforation percentages allowed for elevated air temperatures, while those with minimal perforation did not generate sufficient airflow. However, the screens struggled to maintain comfortable indoor humidity levels during high humid outdoor conditions, prompting further investigation into enhancing performance in high humidity. The study establishes a basis for further research on developing screens that can help mitigate hot and humid climates to create comfortable indoor environments.

KEYWORDS: Mashrabiya, Passive Cooling, Natural Ventilation, Vernacular Architecture, Digital Fabrication.

INTRODUCTION

The name Mashrabiya is derived from the Arabic word “drink” and originally meant “a drinking place” (Fathy 1986, 46). In the past, people would put water jars next to the Mashrabiya screen so that the incoming breeze cooled down the water, while the evaporated water from the jars helped with evaporative cooling in the space. The Mashrabiya has five main purposes: shading, natural ventilation, evaporative cooling, reducing the temperature of the interior, and providing privacy and cultural decorative elements (Fathy 1986). In this study we will be focusing on Texas (USA), where according to the U.S Energy Information Administration, the average electricity consumption is 26% higher per home than the national average, with a large part going to air conditioning throughout the year (EIA 2020).

Mashrabiya screens have continued to be used and developed in modern architecture. They serve as an adaptive skin controlling direct sunlight entering the space, as seen in the Albahar Tower in Abu Dhabi (Holloway 2015), and as a structural pattern, as in the Brick Pattern House (Gaete 2019). Mashrabiya screens have also been incorporated into concrete buildings, such as the Mashrabiya house built in 2011, to showcase cultural values (Jett 2011). Additionally, Mashrabiya took different shapes and materials, and it can be cantilevered, louvered timber wall, louvered window or screen panels. It has also been made from wood, stone and gypsum clay. Currently, there is a growing interest in reviving traditional elements in contemporary architecture, leading to ongoing research on new ways to incorporate Mashrabiya screens in modern buildings (Abdelkader and Park 2017).

Interestingly, a study investigated the Ottoman and Andalusian traditional screens through field work and simulation, including air temperature and movement testing, and light distribution of both screens. The research revealed that Mashrabiya not only controlled natural ventilation but also distributed sunlight better inside the room compared to a window without any type of screen (Salem 2019).

In addition to its cultural significance and versatility in architectural design, the functional benefits of Mashrabiya screens have also been explored in various studies. Some scholars analyzed the use of traditional environmental treatments in achieving thermal comfort, including implementing of Mashrabiya screens (Shahda and Noiser 2021). Other researchers studied sustainable design strategies for mosques, where Mashrabiya screens were used alongside other passive techniques such as thermal mass and stack ventilation (Azmi and Kandar 2019). Some

academics worked on developing a second skin façade based on Mashrabiya functions and cooling techniques. The study showed the possibility of creating a second skin façade on an office building in Arizona (USA) and calculated the potential energy savings that could be achieved (Khadra & Chalfoun 2014). Also, analyzing the aerodynamics when wind hits Mashrabiya screens would help create a self-cool wall depending on venturi effect (Ferwati 2013). An investigation in Egypt influenced the annual energy load by modifying the perforation and depth of the screens. 30% of energy savings were achieved when an external deep perforated solar screen was oriented to the south and west (Sherif et al. 2012). These studies suggest that Mashrabiya screens remain relevant in contemporary architecture and sustainable design practices.

The multiple features and functions of Mashrabiya were emphasized in Alothman's comprehensive literature review showing different ways to test the screens depending on what factors needed to achieve (Alothman 2017). It also should be noted that the effectiveness of Mashrabiya screens can be enhanced when integrated with other passive strategies as revealed by Bagasi, proving that the thermal mass had impacted the results of data monitoring for a Mashrabiya performance in Saudi Arabia (Bagasi 2020). Just like Mashrabiya screens were originally introduced and tested in hot and dry climates, Jali screens are the Indian equivalent which were also developed for that harsh environment. Jali screens are architectural feature comparable to Mashrabiya in terms of function, although they differ in nomenclature and design. Unlike Mashrabiya, evaporative cooling was not feasible when utilizing Jali screens in hot and humid regions. Hawa Mahal is an exemplary structure that showcases various Jali screen designs, with differing opening sizes and depths ranging from 2.5 cm to 11.5 cm (Kumar 2014). Kumar investigated the performance of the screens in the hot, humid, and dry climates of India through field monitoring and laboratory testing of screens with varying perforation percentages and opening sizes to find out how these screens help to mitigate indoor temperature and humidity levels.

The industry of fabricating Mashrabiya screens evolved through history, starting with wooden screens were traditionally made by carving wooden balusters. However, today computer numerical control (CNC) and laser cutting technologies are used with different materials to create various shapes. One researcher created “Cool Brick” as one of the first 3D-printed models inspired by Mashrabiya that creates a passive cooling device that has hollows inside for water to pass through (Fratello and Rael 2015). Currently no physical examples of an architectural-scale 3D-printed Mashrabiya exist.

Despite the extensive research on Mashrabiya latticework, there is a lack of studies exploring its potential to mitigate heat and humidity in hot and humid climates. Advances in modern fabrication techniques now enable the precise alteration of geometrical parameters such as perforation, depth, and opening geometry, thereby offering an opportunity to modulate the airflow of the shading device. Accordingly, this study aims to reintroduce perforated screens with varying perforation percentages and thicknesses to evaluate their performance in the hot and humid climate (ASHRAE 2A) of San Antonio, Texas, USA.

1.0 METHODOLOGY

The primary objective of this investigation is to assess the airflow dynamics facilitated by the devised screens. This evaluation is conducted through two main experiments, indoor laboratory testing with controlled air velocities and outdoor testing in the natural weather. The methodology commences with the design and fabrication of the screens, followed by laboratory testing involving two distinct scenarios and subsequent outdoor testing for the same screens.

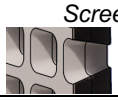
1.1 The testing room

A 1.8 x 1.8 x 1.8-meter testing room was designed and constructed with traditional US techniques using wood studs and plywood with no insulation and two hung windows. Each window is a double pane and measures 91.4 cm by 91.4 cm.

1.2. Design and digital fabrication technique

Four distinct perforated screens were modeled and fabricated based on two main factors: thickness and perforation percentages. Perforation percentages were based on previous studies on old Mashrabiya's performance (Salem, 2019). Each screen measures approximately 91.44 cm x 91.44 cm with varying opening sizes and thicknesses ranging from 5 cm to 10 cm. CNC technology was used to cut the screens from building insulation Styrofoam, a lightweight material that allowed for easy cutting and forming of different sizes and shapes. Then the screens were painted white to reflect as much solar radiation as possible. Table 1 describes the properties of each screen, including its thickness, perforation percentage, and open area ratio. The accompanying image shows the CNC cutting process used to create the screens.

Table 1: Perforated screens properties. Source: (Author 2024)

Properties	*Screens*			
				
Exterior opening size (cm^2)	103	103	161	161
Interior opening size (cm^2)	25	25	58	79
Thickness/ Depth (cm)	5	10	10	5
Exterior perforation percentage	60%	60%	70%	70%
Interior perforation percentage	13%	13%	30%	45%
Sectional angle between ext. and int. openings	26°	14°	14°	14°

1.3. Laboratory testing experiments

Laboratory experiments were systematically conducted within a controlled environment featuring consistent temperatures and regulated air circulation. Wind speeds were induced through a fan calibrated at three distinct velocities. Two specific experimental scenarios were investigated:

1. Screen Placement over the hung window:

In this scenario, each screen was positioned over the open hung window of the testing room, directing airflow exclusively to the lower section of the screen. The primary objective of this scenario was to assess the performance of each screen when employed with hung windows, thereby evaluating their effectiveness in situations where air flows solely through the lower portions of the screen.

2. Screen Placement within window Opening:

In the second scenario, the hung window was removed, and each screen was placed within the window's opening, allowing airflow across the entire perforated surface of the screen. The aim of this scenario was to evaluate the performance of each screen in ventilating a room using either a casement or sliding window, providing insights into their effectiveness in scenarios where airflow spans the complete perforated area.

To ensure standardized conditions, a fan was strategically positioned in front of the screen, operating at three distinct air speeds (2.9, 4.5, and 6.1 Km/h) in accordance with ASHRAE standards (ASHRAE 55 2020). Another time, the fan was positionned with 45° angle from the screens surfance and on speed 4.5 km/h. An outdoor sensor was deployed on the roof to measure air temperature and relative humidity in the testing surroundings. Additionally, twenty-seven interior sensors of the Hobo Onset type were strategically placed as a 3D grid within the test room to visualize air movement during each experiment by measuring air temperature and relative humidity. Indoor air velocity was manually measured at each sensor location using a Hot Wire Thermo-Anemometer with a data logger. The experimental setup is depicted in Figure 1.

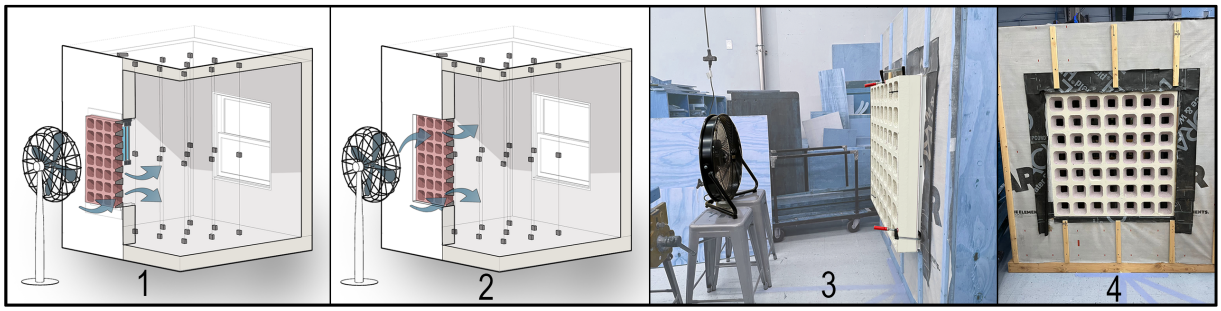


Figure 1: 1- Experiment setup when placing the screens over the hung window. 2- Experiment setup when placing the screen in the window opening. 3+4- examples of experiments setups in the laboratory. Source: (Author 2024)

1.4. Outdoor testing

The testing room was positioned outside in the parking lot of the laboratory building facing south and each screen was placed over the window. The experiment setup included data collection using Hobo Onset sensors (in and out of the testbed) over a continuous two-day period for each screen, with data collection taking place from April 9th to April 23rd, 2023.

It is important to note that the testing room was situated over asphalt, which may have affected the micro-temperature around the room. This limitation has been considered when interpreting the results. Figure 2 provides a visual representation of the experiment setup and some images of the experiment.

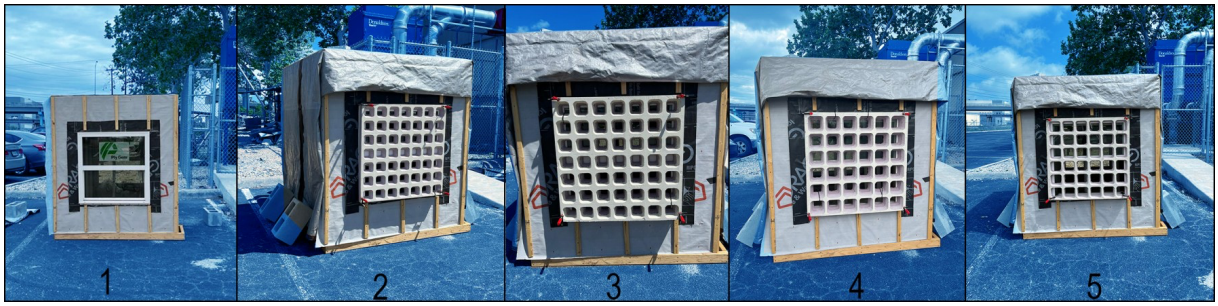


Figure 2: 1: Outdoor setup for the testing room. 2-5: images of the screens following screens order as Table 1. Source: (Author 2024)

2.0 RESULTS AND DISCUSSION

This section presents the outcomes of the digital fabrication and CNC cutting processes, as well as the analysis of field data, which is divided into two primary parts. The first part pertains to laboratory testing, where airspeed was regulated, and encompasses:

- Testing each screen with and without the window at three different air speeds (2.9, 4.5, 6.1) Km/h.
- Placing a fan at a 45° angle from the window opening with an air speed of 4.5 Km/h for all four screens.

The second part was outdoor testing, which include collecting data continuously for at least 48 hours for each screen placed on top of an open hung window in the laboratory's parking lot.
The results consist of field measurements of indoor and outdoor air velocity, air temperature, relative humidity, and light intensity.

2.1. Design and digital fabrication technique for the four screens

The Rhino software facilitated the generation of diverse geometries and opening depths using Grasshopper, enabling the manipulation of certain parameters to achieve numerous shapes and precise angles. In this study, a fundamental geometry was selected to regulate solely the thickness and opening sizes. The external and internal opening dimensions differed from one another. For ease of testing, the author employed Styrofoam, though more eco-friendly materials are recommended for future investigations. The CNC milling machine took about 6 hours to cut the 5cm thick screens, while the 10cm thick screens were fashioned by joining two 5cm pieces with a specialized foam adhesive. In sum, the CNC cutting process required over 15 hours to accomplish.

2.2. Laboratory testing with controlled air velocities

Based on Table 2 and Figure 3, the screens showed better performance in allowing air to pass through without the window than when half of the screen was used for ventilation. The screen with 30% perforation and 10cm thickness showed the best ability to let the air pass through and distribute the air inside the interior space in all scenarios. Table 2 shows that the percentage of outside received air velocity decreases as the exterior velocity increases. This could be due to the air curtains created when air turbulence hits the screen. The most significant drop in air velocity can be seen when the exterior air velocity was 6.1 km/h.

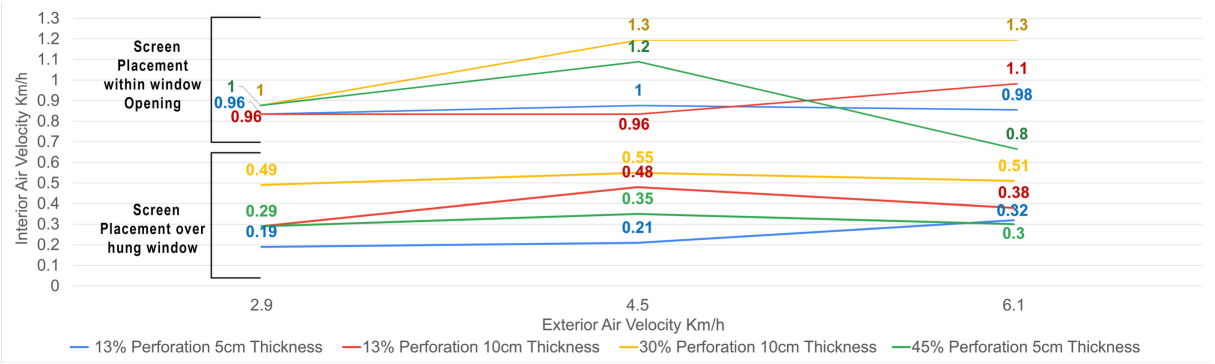


Figure 3: Comparison between the screens in the two different scenarios. Source: (Author 2024)

Table 2: Test results of the four screens when tested over the hung window and without it. Source: (Author 2024)

		Screens											
	Thickness/ Depth (cm)	5			10			10			5		
	Interior perforation percentage	13%			13%			30%			45%		
Over hung window	*Outside wind velocity Km/h*	2.9	4.5	6.1	2.9	4.5	6.1	2.9	4.5	6.1	2.9	4.5	6.1
	Inside wind velocity Km/h	0.19	0.21	0.32	0.29	0.48	0.38	0.5	0.55	0.51	0.29	0.35	0.3
	% velocity of outside received	7%	5%	5%	10%	11%	6%	17%	12%	8%	10%	8%	5%
	Average air perforation %	6%			9%			13%			8%		
Without the window	*Outside wind velocity Km/h*	2.9	4.5	6.1	2.9	4.5	6.1	2.9	4.5	6.1	2.9	4.5	6.1
	Inside wind velocity km/h	0.96	1.04	0.98	0.96	0.96	1.08	1.02	1.3	1.3	1.03	1.21	0.8
	% velocity of outside received	33%	23%	16%	33%	21%	18%	36%	29%	21%	36%	27%	13%
	Average air perforation %	24%			24%			28%			25%		

Upon analyzing and generating air mappings for air movement at 1m height inside the testbed for different scenarios. Figure 4 shows some examples of them, and the following observations were made:

- The internal angle of the screen functions as an impediment to the airflow within a certain angle, redirecting the air to the opposite side of the room. Figure 4-1 shows one example when the screens faced 45° airflow from the fan at a speed of 4.5Km/h.
- Augmenting the direct wind speed results in heightened turbulence within the room, causing the air to circulate in circular patterns. See Figure 4-2, when the fan speed was 6.1 km/h on screen with 13% perforation.
- Increasing the thickness of the screen creates a lengthier pathway for the air creating venturi effect, consequently accelerating its passage. In 3 and 4 of Figure 4 below is a comparison between the two screens with same perforation percentages but different thickness in air mapping when fan speed was 6.1 km/h. The screen with higher thickness (Figure 4-4) generated higher indoor air velocities.
- Expanding the opening sizes of the screen allows more air to pass through, albeit at lower velocities.
- The screen featuring 30% perforation and a thickness of 10cm demonstrates superior air distribution within the space, leading to more similar conditions throughout the room.

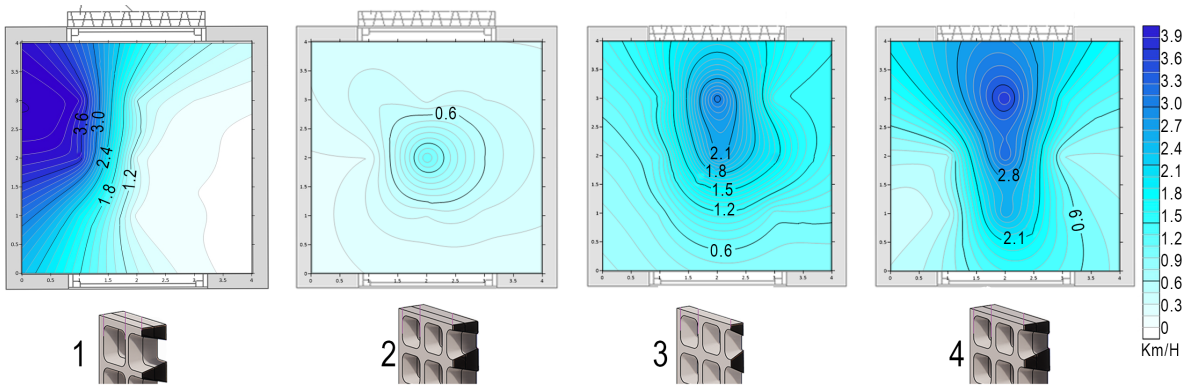


Figure 4: Air mapping examples for four different scenarios. Generated in Surfer software. Source: (Author 2024)

2.3. Outdoor testing-temperature and humidity analysis

Starting with the screen of 13% perforation and 5cm thickness, the prevailing wind direction on the first day was primarily from the east and north, exhibiting modest velocities ranging from 4.8 to 8.0 km/h. External humidity levels averaged 80%, while internal humidity stood at 75.3%. The indoor temperature closely mirrored the outside conditions, fluctuating within the 21 to 26.7°C range and peaking at approximately 24.4°C, corresponding to the highest observed external temperature as illustrated in Figure 5 (tope left). The subsequent day, experienced hotter and sunnier weather, with external temperatures reaching 35.6°C and internal temperatures rising to 30.6°C (ΔT= 5°C). The prevailing wind originated from the north and east, with average velocities of 12.9 to 16.1 km/h. Although humidity remained elevated during the morning, internal levels consistently ranged between 55% and 66%. The increased wind velocities on the second day contributed to moderating the room temperature compared to the initial day. Despite the lack of insulation in the room, the small openings in the screen facilitated natural ventilation, assisting in maintaining lower peak temperatures within the space.

Next, the screen with 13% perforation and 10cm thickness was tested, Figure 5 (top right). The weather conditions were marked very similar for both days of testing by scattered clouds and sunshine, with the highest temperature

reaching 33.2°C. Inside the room, the maximum temperature was 30.6°C (ΔT= 4.8°C). The peak wind speeds during testing occurred in the afternoon when the heat was at its maximum, predominantly originating from the southeast at velocities ranging from 8.0 to 11.3 km/h. The exterior relative humidity was higher in the morning, reaching its peak at 79% on the first day, while the interior relative humidity reached 70%. On the next day, the maximum exterior relative humidity was 81%, while the interior relative humidity was 74%.

When the screen of 30%perforation and 10cm thickness (seen in Figure 5 bottom left), the weather conditions on both days of testing were quite similar, with mostly cloudy skies and high wind velocities ranging between 16.1-20.9 km/h. The wind direction was primarily from the east, with some coming from the south. On the day when the highest exterior temperature was recorded at 36.6°C, the interior temperature reached 32.3°C (ΔT= 4.2°C). The high wind velocities may have contributed to the elevated interior temperatures. The maximum exterior relative humidity reached 85%, while the interior relative humidity was 81.3%, which is still considered high.

During the first day of testing of the last screen with 45% perforation and a thickness of 5 cm (figure 5 bottom right), the wind primarily came from the north and east with velocities ranging from 11.3-14.5 km/h, while the highest outside temperature reached 35.5°C and the inside reached 33.3°C (ΔT=2.2°C). The following day, the wind shifted to the south and east, and the higher temperature peaked in the afternoon. Notably, the inside temperature was very close to the exterior temperature. By comparing the wind direction of both days, the temperature was higher indoors when the wind was directed to the screen on the south side, which probably caused higher temperature levels on the second day of testing. The relative humidity was similar to the exterior in the afternoon on the first day, while in the morning of the second day it reached a maximum of 54.9%, and inside the room, it was 44.3%.

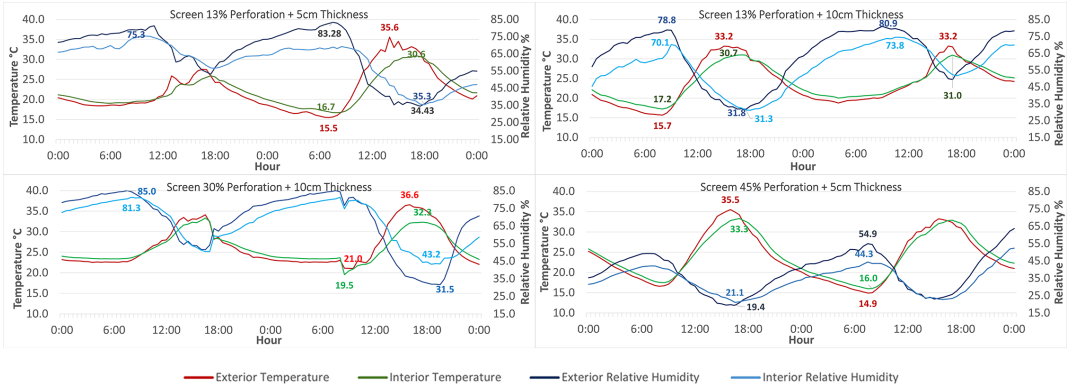


Figure 5: Interior and exterior temperature and relative humidity of the testing room for each screen. Source: (Author 2024)

For 24 hours, the room's window was left open without a screen and data is shown in figure 6 below. According to the data, the indoor temperature closely mirrored the exterior, slightly exceeding it at times. When the outside temperature reached 30.6°C, the indoor temperature registered at 30.7°C (ΔT= 0.1°C). Indoor relative humidity peaked at 76.1%, while exterior humidity was 82.4%, both considered high. The wind, mainly from the east and some from the south, averaged between 14.5-20.9 km/h. The open window allowed warm air and direct sunlight, creating suboptimal thermal comfort. In contrast, perforated screens effectively moderated indoor conditions by allowing airflow, proving more efficient than simply opening a window.

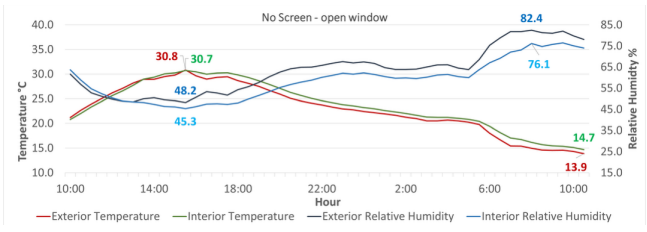


Figure 6: Interior and exterior temperature and relative humidity of the testing room with open window and no screen. Source: (Author 2024).

Based on the gathered data, it is evident that the screen with 5 cm of thickness and 13% perforation was the most effective in maintaining a cooler room temperature when the external temperature reached its peak (ΔT= 5°C). Similarly, the screen with 10 cm of thickness and 30% perforation also demonstrated effectiveness in moderating indoor temperatures (ΔT= 4.2°C). Conversely, the screen with 45% perforation and 5 cm thickness proved less effective in moderating room temperature compared to the other screens. While relative humidity closely matched exterior levels in most instances, the screen with 13% perforation and 5 cm of thickness unexpectedly created a significant gap between the maximum exterior humidity and the interior humidity.

2.4. Outdoor testing-light intensity analysis

The direct sunlight inside the space can cause higher uncomfortable light intensity and glare. The below shadow study for the screens helps to understand the times of year the sun penetrates indoors the most. The four designed screens have equal opening depths from all four sides. In the case of the screens facing west, during hot summer

days, the sun will penetrate the screens with 5cm thickness and high perforation percentages (Figure 8 left). Only the screen with 10 cm thickness and the least perforation will prevent direct sunlight penetration during the hottest hour of the day in summer. Sun angles on different dates are shown in Figure 7.

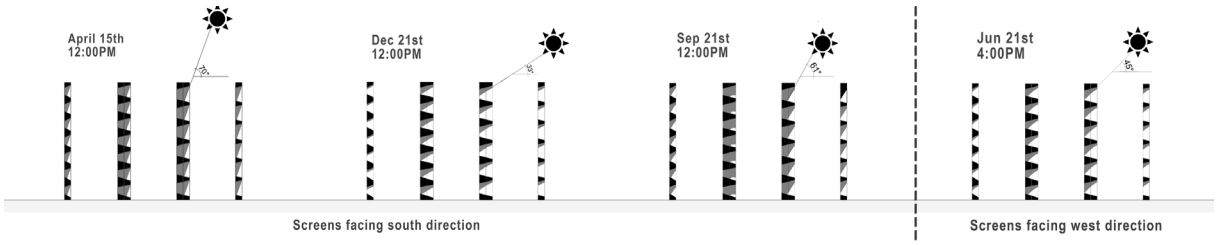


Figure 7: Sun angle on the four screens when facing south on the day of testing, winter solstice, and autumnal equinox. Sun angle on summer solstice when facing west. Source: produced via Revit simulation. Source: (Author 2024)

In the case of the screens facing south as this research investigates, the direct sunlight is facing the screens at noon, and the direct sunlight does not enter the room when using a screen with 13% perforation and 10 cm thickness the whole year, because the sun did not penetrate when it was on its lowest angles in December. When the sun angle increases during spring and summer days, there is a complete absence of sunlight penetration through all screens from the spring equinox to the autumn equinox. That also means the sun does not penetrate on June 21st at the summer solstice because the sun is higher. Starting from autumnal equinox, direct sunlight begins to penetrate the screen with the highest perforation percentage and lowest thickness, namely the 45% perforation and 5 cm thickness screen in this case. This pattern continues until the sun angle starts to decrease again, reaching its lowest point during the winter solstice.

Light intensity was monitored at 30-minute intervals during screen testing, with room sections divided for analysis (see Figure 8). Afternoons saw acceptable average intensities (323-646 lux) for 13% and 30% perforation screens, meeting ASHRAE standards for spaces like cafeterias and classrooms. However, morning and evening intensities were insufficient, requiring additional artificial lighting.

The 45% perforated screen, with higher openness and 5 cm thickness, allowed intense sunlight, resulting in brightness exceeding 1,076 lux in the first two sections—too high for comfortable indoor lighting, causing glare and discomfort. Conversely, the 30% perforation screen showed high intensity near the window but, with 10 cm thickness, evenly distributed light, reducing glare and preserving outdoor views. With an opening size of 0.84 square meters, the 30% perforated screen achieved a balance in controlling indoor light intensity. Data collected without shading devices revealed unsuitably high light intensity, emphasizing the need for such devices to regulate sunlight.

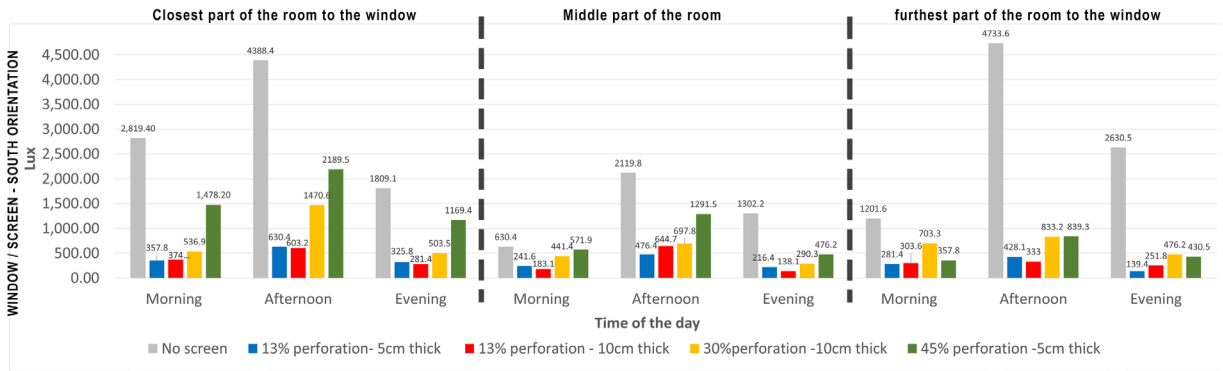


Figure 8: Light intensity for each screen in each room section based on the location from the window/screen placement. The window is located on the left of the graph. Source: (Author 2024).

CONCLUSION

This research aimed was to identify the most advantageous combination of perforation percentages and thicknesses that yield optimal results for Mashrabiya screens in hot and humid climates. In determining the optimal perforation percentages, the traditional Mashrabiya screen percentages served as a baseline to initiate the venturi effect. Subsequently, these screens underwent testing with varying air velocities, both in front of an open hung window and without the window. The study involved measuring interior and exterior air velocities and visualizing air movement inside the room under different scenarios using Surfer software. Outdoor testing in San Antonio, Texas, USA, provided data on air temperature, relative humidity, and light intensity for each screen.

Results revealed that the performance of each Mashrabiya screen is unique, dependent on perforation, opening size, and thickness. The screen with a 5 cm thickness and 30% perforation was most effective in ventilating the room, reducing temperature, and distributing light while blocking direct sunlight. However, real-world testing uncovered a limitation in maintaining comfortable interior humidity levels during outdoor tests, necessitating further improvements for high-humidity conditions. The study underscores the need for further research to implement Mashrabiya screens as a passive cooling technique in buildings facing extreme heat in hot- humid climates.

This investigation forms the groundwork for exploring additional variables and introducing new cooling devices to enhance the cooling efficiency of screens. Future research avenues include exploring factors such as screen shape, orientation, and design, conducting real-world tests in diverse settings, and evaluating energy efficiency compared to traditional cooling systems. These endeavors aim to contribute to developing of passive cooling solutions for our built environment.

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Inhabiting The Plastisphere? – Architectural Making As a Prelude To Transdisciplinary Sense Making Of Plastics In The Environmental World

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ABSTRACT: In the plastisphere waste-landscapes formed by human consumption are discarded products that often become the place of inhabitation of various inherent earth, and air bound microorganisms (Amarel-Zettler et al. 2020). Yet, whereas the amounts of plastics piled up in our environment and inside our bodies are vast, increasing, due to the everlasting properties of the material, plastics are alien to us (humans of privilege) as a place of inhabitation. Our relationship to plastics is uncomfortable and emblematic of our overconsumption and its social, environmental and economic consequences. Posing the question of inhabitation of the plastisphere, this paper searches a direction to link the microscale potential for nonhuman colonization of disposed plastic as an architectural potential in addressing the pressing macroscale need for decolonization.

The paper hypothesizes that there are qualities to be nurtured in a transient and contingent manner in pursuing a tectonic joinery of ecological relationships between a material, colonizing organisms and resulting performances, inviting opportunities for the benefit of both the needs of human society and the needs of our natural environment. Consequently, this research engages in material experimentation, and the aptitude of a material to be colonized by one or several groups of living organisms without necessarily undergoing any severe deterioration. The paper presents a series of 1:1 prototypes exploring a possible inhabitable afterlife of, specifically disposed plastics, through an iterative process intersecting architectural knowledge and making.

In conclusion, the paper discusses the potential of these prototypes as preludes to the formation of transdisciplinary research collectives and more towards uncovering a viable embodiment and afterlife of disposed plastics in the environmental world through its tectonic incorporation in the built environment.

KEYWORDS: Disposed plastics, Architectural Making, Tectonics, Transdisciplinary, (De)colonization

INTRODUCTION – PLASTIC AS AN EMBLEMATIC CASE

The challenges and potentials of meaningful implementation of new materials in architecture has been a key subject throughout architectural history. Perceived as the DNA of all building and space construction, material types and composites have, through articulation and development, kept at pace with our own societal advancements contributing to demands laid down by us (humans of privilege), for example social, health and welfare societies, influencing approaches to building development as a consequence. Material processing and development were a cornerstone for The Arts and Crafts Movement, that further influenced social and human wellbeing developments of the Garden City Movement. Material technology and production advancements accelerated though the High-Tech era, and up to date contemporary technical and material advancements embrace ecological and digital fabrication crafts, technics and thinking, a subject that has become increasingly present with the increasing pace by which material and construction technology advances (Semper, Mallgrave, and Robinson 2004).

With technological advancements, the metabolism of the built environment has increased its pace, and we are by now well aware of the magnitude by which architectural construction affects the global environmental imbalances that govern a viable path forward (Rockström and Moberg 2014). So, through a quest to bring material advancements as a fundamental player into advancing our own well-being, the immensity and cocktail of unending new material consumption, coupled with our lack of regard to the consequences of the metabolism of the built environment through a flow of materials, has contributed to environmental imbalances, defeating the overriding objectives of creating better societal environments and advancements.

We (humans of privilege) are in no position to continue our misconceived fancy of the new, nor at the scale of architectural construction as a whole nor at the scale of single material applications. Material advancements, though necessary to satisfy current and future demands of our built environment, needs to shift towards drastically slowing down the flow of new materials that govern the current construction practice by inhabiting what is already there and avoid historical patterns and behaviors of demolition and deposing of valuable material regarded as waste (Reductionroadmap.dk). The quest for ingenuity in the gradual exchange of materials, ‘stoffwechsel’ (Moravánszky 2018), no longer solely concerns meaningful architectural implementation of new materials but requires the development of an architecture of waste materials that we are culturally detached from.

This research therefore investigates this challenge at the micro scale of the material itself using plastics as a case. Plastics are associated with low quality and something cheap and of no, or little value. We therefore often dispose of the material after a single, or short-term use. (Geyer, Jambeck, and Law 2017). As a case, our relationship to plastics is uncomfortable and emblematic of our overconsumption and the social, environmental and economic consequences. We embrace the lightness, strengths, durability and ductility of the various chemical chains developed in our laboratories to further develop the needs of society, yet are uncomfortable with the notion of coexistence with this synthetic material, and pursue its removal from our lives, rather than to coexist and colonize. Removal, as a preferred action, has resulted in well documented negative consequences of our global environment. Since plastics invention (Science Museum. UK) today the world collectively has produced 8 billion tons, of which a colossal 6 billion tons is regarded as waste (Mckinsey & company), that is, unwanted material that contributes to that waste landscape of redundancy and illuminates our uncomfortableness with the notion of coexistence of our anthropogenic product (Derraik, 2002; Thompson et al., 2004; Corcoran et al., 2009; Law et al., 2010).

Coexistence on our planet with plastic as a symbol of anthropogenic impact on the environment is uncomfortable, and everlasting. Plastic can degrade biologically but is a slow process (Kulshreshtha 1992; Shah et al. 2008; Cooper and Corcoran, 2010). Plastic in our environment is persistent (Gregory and Andrady 2003) and reacts to environmental changes in temperatures due to polymers inherent ductility. In certain warm climates softened and melted plastic debris waste has fused and mixed with substrates creating a new type of material discovery referred to as plastiglomerate (Corcoran, Moore and Jazvac 2014). Plastiglomerate has been formed by heat – natural and manmade (fires) whereby there is a fusion between plastic and substrate materials such as rocks, and new formations are made. Plastiglomerate is, by definition, not a rock; rocks are formed naturally, whereas plastiglomerate is composed of anthropogenic products (plastic) shaped natural actions. Nature therefore has been instrumental in this case in establishing a state of coexistence that we as humans find difficult in the least, and challenging at the most.

Nevertheless, actions, responses and reactions of manmade material composites to our natural environment is a focus of interest for this research in an attempt to explore more amenable relationships to plastics rather than that of uncomfortable and an emblematic of our overconsumption, and to promote long term patterns and behaviors with materials often regarded as waste (Geyer, Jambeck, and Law 2017). Consequently, this research investigates both means of laboratory-based fabrication and nature induced patination as an entrance by which to explore a possible inhabitable afterlife of, specifically disposed and recycled plastics, in and through architecture towards a wider transdisciplinary understanding of how to make sense of plastics in the environmental world and how we as humans of privilege can coexist in meaningful ways with our waste material.

In this matter the paper presents a series of prototypes that result from physical modeling and testing at real scales architecture of and for inhabitation, both physically and emotionally. A significant attribute of the test cases was an acknowledgement of the value of time through deterioration, patination, erosion and non-human colonization, that gives us avenues for engagement, an understanding of our material connections and avenues for inhabitation of the plastisphere. Processes of fabrication and assembly also encouraged other unforeseen consequences of the aesthetic that facilitated other transformations of plastics into a viable place of inhabitation for human and non-human species alike and entry points into engaging with disposed plastics as an anthropogenic product of our time.

1.0 METHODOLOGY

1.1 Patination as an entrance

Patination of objects can be seen as a process of change to a material and its surfaces (Pallasmaa 2016). Materials exposed to active daily and seasonal environmental conditions can begin to change. It may be colour bleach from the sun, dirt accretions accumulated through bombardments of airborne organic material through wind and rain, or physical weathering of sharp edges to more smoother geometries by receiving live forces from nature. Humans' use and contact with materials also adds to patination through the process of time and can make visible the use and history of an object and the material it is made from.

> it is in that golden stain of time, that we are to look for the real light, and colour, and preciousness of architecture; and it is not until a building has assumed this character, till it has been entrusted with the fame, and hallowed by the deeds of men, till its walls have been witnesses of suffering, and its pillars rise out of the shadows of death, that its existence, more lasting as it is than that of the natural objects of the world around it, can be gifted with even so much as these possess of language and of life. (Ruskin 1849, 162-182)

The patina aesthetic was further popularized by art critic John Ruskin in the 19th century with his romanticizing of the golden stain of time (Ruskin 1849, 221). The broadest definition of patina adds the effects of human use to the effects of natural processes of time. This can be understood as “cultural weathering” (Heath 2016) and includes everything that makes visible the history of an object and how it was used.

The methodology of cultural weathering to encourage states of coexistence and engagement through engaging in new processes of production in this research was examined therefore by two principal methods, energy injection and human insemination techniques.

1.2 Energy injection to foster transformation consequences

In a process of material transformation from ‘raw base product’ to a useful designed and fabricated component, heat needs to be applied to plastic so that it bonds, softens and can be directed to desirable casts and formwork. The plastic will then cool, and processes are carefully controlled to ensure no imperfections of shrinking, flashing, an excess of material, and air bubbles etc. This research explored, through real scale testing, implications of encouraging transformations of the material and imperfections of heating and cooling by consciously not controlling the process of fabrication of components in normal manners, with specific goals to explore its habitation potentials. This was done by not restricting movement of the material whilst cooling, over ‘cooking’, under ‘cooking’, open formwork rather than pressed and closed within controlled formworks, and encouraging gravity to maneuver the material in semi-uncontrolled manners whilst the plastic is soft. With a less rigorous control one can encourage other unforeseen consequences of the aesthetic and facilitate other transformations of plastics into a viable place of inhabitation for human and non-human species alike.

1.3 Human insemination techniques to encourage habitation

To encourage places of inhabitation and colonization for human and non-human species alike the research explored, through real scale testing, implications of adding organic alien compounds during the process of form making. With active participation through embedding alien organisms, the plastic reacted by cracking open in part, and embedded the organic material into the body of the plastic and its surfaces to create habitats for human and non-human spolia that establish abilities for colonization and bio receptivity. Through an act of adding biogenic organisms’ materials started to come to life through uncontrolled responses and challenged our industrialization processes of material production that usually consciously eliminates growth and alien habitation and colonization’s. The alien materials ranged from seaweed, earth, sugar, salt, horse manure - all easily biodegradable but all providing nutrient sources as substrates for organic growth, and all encouraging the plastic to respond in different ways.

2.0 FINDINGS – PROTOTYPING THE INHABITATION OF PLASTICS

The research follows iterative prototyping processes where knowledge has been accumulated via explorations of specific material performances, from laboratory to construction mock-ups focusing on the architectural qualities embedded in control of production techniques and facilitating longer term patinas of material surfaces to extend the aesthetic beyond common judgements. Experiments have therefore been focused on how the inherent material qualities drive a design brief towards specific investigations to explore aesthetics induced through production, patinas from human and non-human forces, and colonization obtained over time while exposed to external climate conditions.

Experiments carried out through iterative prototyping processes can be categorized into 4 chronological parts: 1, Polycarbonate Blue Wall; 2, Incubator Growth; 3, Green Habitations, and 4, Plastic Pringles.

2.1. Polycarbonate blue wall

The material type of interest was recycled polycarbonate that was formed through heating in metal forms with applied pressing with jigs on the top surface to establish imprints through making and cooling. Jigs were made to encourage pressing of a top plate and to present relationships between plastic and human interactions. Two jigs were constructed that could be placed upon the metal frames. The first was an x-shaped jig (fig. 1) consisting of 9 bolts that could press upon the flexible top plate. This allowed pressure to be exerted down onto the top plate whereby the pressure could be adjusted. It did not however allow the possibility of lifting the top plate. A second jig was therefore constructed (fig. 2). This consisted of 6 evenly distributed pressure points. 3 were made to exert pressure down, and 3 to lift the top plate up. These were welded to the top plate meaning there were more possibilities of regulating the specific force and contact with the top plate to the polycarbonate plastic.

Through a simple production process, it was difficult to be extremely accurate with exact temperatures, pressure and time being exposed to heat. Cleaning and deforming of the metal forms over time also became factors difficult to control resulting in visible traces of human interference. All these partially uncontrollable actions influenced the overall characters of the components. Some were under ‘cooked’. Some over ‘cooked’. Some free from dirt and others stained by the metal rust and human interference (Getting the plastic out of the mold).

All imperfections induced as consequences of the human process of making developed a methodology of influencing the design parameters - that is through production and fabrication a design intent became responsive to the results and ‘teased’ the component ensemble design demonstrating ways of navigating between the ‘dead’ non-human material of plastic, and human actions. The final ensemble of components has been assembled as a facade and has been placed outside to test and encourage long term patina to study how an artificial material that has been produced by semi-controlled methods can engage in natural processes and thereby promote aesthetic consequences and qualities.



Figure 1: Polycarbonate panel showing the x-shaped jig position. Source: (Author 2022)



Figure 2: Second jig consisting of 6 evenly distributed pressure points. Source: (Author 2022)



Figure 4: Detail of Polycarbonate panel assembly showing collage of imperfection characteristics created by top plate pressure application. Source: (Author 2022)



Figure 5: Polycarbonate panel assembly – façade - showing collage of imperfection characteristics created by top plate pressure applications. Source: (Author 2022)

2.2. Incubator growth

The material type of interest was recycled HDPE shredded plastic that was sourced from a domestic recycling centre and formed through heating piles laid on to metal trays. Recycled plastic was shredded and the shavings mixed with an energy rich garden earth that, when heated created a vast collection of small cavities. These holes became places for micro-habitations that was encouraged whilst in a light and heat incubator environment. By not using specific molds and frames and relying on the natural formation and inherent angle of repose of the composite material when piled up broke down thresholds between controlled and non-controlled environments. When heated, the plastic bonded and sank to a flatter formation and fused, in part, with the earth. Within an incubator environment mycelium and moss was encouraged to grow thereby presenting a new composite of co-existences between anthropogenic products (plastic) and non-human existence.



Figure 6: Mycelium and moss growth in an incubator environment. Source: (Author 2023)



Figure 7: Mycelium and moss growth in an incubator environment. Source: (Author 2023)

2.3. Green habitations

The material type of interest was industrial processed recycled HDPE that was formed through heating in metal forms with no applied pressing. Cavities were created during the melting process by adding organic material to encourage micro-habitations. The alien materials ranged from seaweed, earth, sugar, salt, horse manure, water, sawdust - all of which are easily biodegradable. Water sprayed on to the plastic when hot, was in particular rather successful to encourage cavities, or bubbles of air that were formed through steam. Seaweed also reacted well to reacting with plastic when hot, also creating air cavities, and generally fusing with the plastic to create a well-bonded composite. Sugar was tested as well due to the sugar content in seaweed. Sugar proved to be very instrumental in increasing the overall volume of the final component in the same way as yeast expands flour during the baking of bread. The physical experiments have been placed outside to test and encourage long term colonization through non-human natural processes.

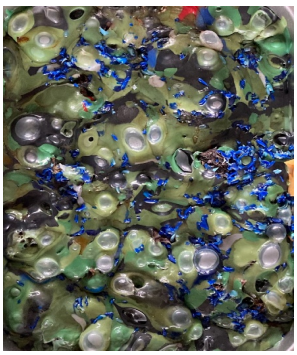


Figure 8: Experiments with applying water to the hot composite of plastic and seaweed. Source: (Author 2023)



Figure 9: Experiments of placing the composite panels outside to test and encourage long term colonization through non-human natural processes. Here the plastic has been mixed with seaweed and sawdust. Source: (Author 2023)



Figure 10: Allowing gravity to allow the hot plastic to sump and stretch in the mold. Source: (Author 2023)

2.4. Plastic pringles

The material type of interest was industrial processed recycled HDPE. The material was not laid into specific molds and frames but, like 2, Incubator Growth, relied on the natural formation and inherent angle of repose of the composite material when piled up. When heated, the plastic bonded and sank to a flatter pancake-like formation and was left to cool. As the plastic cooled it began to naturally deform. Plastic will shrink back to its original volume before being heated - and expanded - usually around 10% at its maximum. Usually, this is calculated in any plastic casting processes and controlled with specific formwork. As the plastic piles were not placed in a mold and only laid out on a metal plate, it was completely unpredictable how the plastic would deform and reform. The thickness of the plastic tended to indicate that the thicker the plastic, the less likely it would deform, meaning the outer edges of the components bent and twisted the most, usually in all 3 axes, creating a double curve-like form similar to the shape of the common crisp, ‘pringles’. Through kinetic explorations of natural processes through cooling, new composites were produced to challenge our own associations of plastic as a usually well controlled material serving the principle role of providing a product for our own existence.

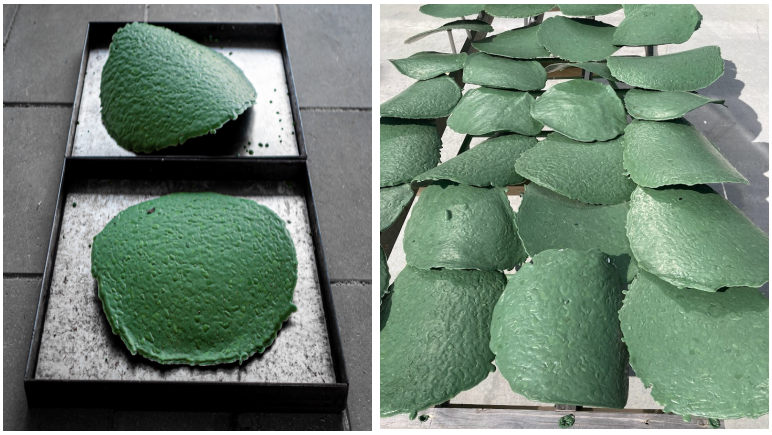


Figure 11: Plastic bent and twisted when cooled. Source: (Author 2023)

3.0 DISCUSSION – ARCHITECTURAL MAKING AS PRELUDE TO TRANSDISCIPLINARY RESEARCH

A recurring focus of the research is an attempt to discuss the perspectives of the work towards transdisciplinary environmental sense making-research of plastics in our societal, and environmental world. There are embedded relationships between the materials we manufacture and use - and eventually discard - and our own emotional attachment, or detachment. That is to say, we have a difficult relationship with our own material production, particularly with increasing concerns in respect to our own welfare and well-being, and the world as a whole as our environment attempts to navigate a coexistence of our anthropogenic products (Derraik 2002; Thompson et al. 2004; Corcoran et al. 2009; Law et al. 2010).

Plastic is present and influential in our lives. We have proved through our own daily existence a complete dependency of this man-made product, yet it is alien to us (humans of privilege) as a place of inhabitation. Plastics are associated with low quality, and even in our language we refer to plastic as a metaphor to describe the cheap and the fake. Disposal of the material after often short-term use has become our preferred pattern of behavior (Geyer et al. 2017). Disposal meaning, out of sight, out of mind. So, do we think of plastic in these detrimental terms because of the material itself, or because of our behavior of use and disposal, or because of our own difficulty as a place of inhabitation, coexistence and colonization - human and environmental?

The research production has been developed and processed through material experimentation and engagement through processes of fabrication as an attempt at outlining transdisciplinary perspectives by using the prototypes as preludes and means of communication and reflection of our own perception of an anthropogenic product and our behavior through use and disposal. Ensembles of multiple - usually anthropogenic products - in our built environment creates space and atmosphere, thereby intrinsically bonding material with our immaterial realm of human perception, imagination and comfort. (Pallasmaa 2014). The research focuses on plastic as a material that is very present in our day to day existence and our survival, and discusses how embracing a synthetic materials' natural processes of transformation when exposed to external climates and alien colonizations can allow places for inhabitation through our cognition and emotional connection, acknowledging that there is no cognition without emotion, even though we are often unaware of the emotional aspects of our thinking to challenge our relationships, judgments and preconceptions (Johnson 2007). An architectural space is perceived with our very existential experience and cognition. As soon as we have made first-hand judgment and assessed a place as enjoyable, inviting or other, we become attached to certain values. Ensembles of multiple materials stacked, screwed, nailed, glued that make our built environment require from us a stand point for engagement and emotional inhabitation, and comprehensive grasping of the ambience of a spatial entity can be understood from the point of view of biological survival (Pallasmaa 2014).

The research suggests that means for confronting emotional engagements to navigate a coexistence of waste of our anthropogenic products can be made possible through an act of both applying energy, and inseminating non-biogenic material with biogenic products. Through applying energy and non-human insemination, plastic starts to come to life and offer unpredictable responses. This unpredictability allows us as humans to engage in other ways and displace the shackles we bear when addressing our own unforgiving waste by offering insights into how timeless, artificially laboratory constructed products can, through wear and tear, follow and replicate our own course of adaptation - and aging even - as we navigate through time.

The experiments conducted consciously encouraged responses by offering processes of production that were uncontrolled when compared to usual processes of producing plastic products. The approach of offering significant reduction of control established imperfection to flourish and acknowledged nature's way of establishing states of coexistence of anthropogenic products (plastic) like plastiglomerate (Corcoran, Moore, Jazvac 2014) in our very lives and the environments we construct.

> Imperfection is in some sort essential to all that we know of life. It is the sign of life in a mortal body, that is to say, of a state of progress and change. Nothing that lives is, or can be, rigidly perfect; part of it is decaying, part nascent….. And in all things that live there are certain irregularities and deficiencies which are not only signs of life, but sources of beauty. All admit irregularity as they imply change; and to banish imperfection is to destroy expression, to check exertion, to paralyze vitality."
> (Ruskin 1853)

A typical building material must also confront an external environment that too is not controlled. Material is susceptible to heat, to rain, to snow, to wind, to ultra violet deterioration. All live forces as such of which materials naturally act and react through weathering, erosion, patination, discolouring, and producing chemical reactions like rust, resistance and accommodation.

> Geometry and form speak of permanence, whereas materials – through the very laws of nature – trace the passing of time. Modernity has been obsessed with novelty and a perfectionist formal language that does not register this. As deterioration, erosion and entropy are the unavoidable fate of all material constructions, the ideal of perfect and unchanging form is bound to be a momentary illusion, and eventually a false ideal. (Pallasmaa 2016, 57)

Biogenic and non-biogenic material engineering presented in this work has been conducted in an intuitive and low technological framework. Temperatures needed for encouraging transformations are akin to baking bread. Even the time spans are similar. There is no specialist equipment needed and the components produced reflect that. The very processes adopted give us opportunities and scope for scrutinizing the potential of plastics as a viable place of inhabitation for human and non-human species alike, through an embodied architectural confrontation with the material and offers an exchange between materials, as building blocks of our built environment, and the immaterial realm of human perception and imagination. Transforming synthetic material through hands-on and basic manufactured processes, coupled with natural processes of transformation when both mixed with alien biogenic materials and exposed to the external climate can allow places of inhabitation and

challenge our relationships and perceptions that are often alien to us (humans of privilege) as a place of inhabitation.

CONCLUSION

Contemporary building construction provides frameworks for the clear needs of human comfort and habitation whilst navigating with an unpredictable external environment. In pursuit of better, environmentally sensitive building constructions and envelopes, we need as a profession to engage in environmental responses, not as rejection in keeping nature at bay, but through inclusion. To 'work' with nature. To nurture forces that materials confront and embrace accretions time and weather impose. This research has attempted to embrace single building components, the processes of making and the processes of contaminating anthropogenic products (plastic) with nature-based materials to facilitate a closer discourse between biogenic and non-biogenic materials and encourage states of coexistence that we as humans can have a closer affiliation with. The work suggests through acknowledgement of environmental forces and attributes a closer affiliation can be achieved. The work encourages an examination of means of production, but has remained at the small scale and although suggests a non-laboratory approach it is nevertheless a product of small-scale laboratory like testing. To fully embrace this type of material investigation the work needs to be scaled up and engage in mass production-like techniques and begin the difficult discourse between what we do, and, what we should do.

In conclusion, this paper discusses the potential of manufacturing prototypes as preludes to the formation of transdisciplinary research collectives juxtaposing chemistry, engineering, psychology, sociology (Gauri, Hinge and Otzen 2023) and more towards uncovering a viable embodiment and afterlife of disposed plastics in the environmental world through its tectonic incorporation in the built environment.

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The Modern Trinity; Affordable, Sustainable, Urban Infill Housing

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ABSTRACT: We are in an affordable housing crisis yet there are large areas of our cities with abundant vacant infill sites with the potential to address this problem. For example, in the Lower North District of Philadelphia about 3 in every 10 rowhome properties are vacant. Rather than recreate the former cramped row homes, this project proposes a new typology of smaller more affordable homes reoriented on the site to provide greater access to sunlight, fresh air, and green space. While not every location is feasible for this approach, the Lower North is ideal because 1. It contains an abundance of 800 potential, vacant infill lots, 2. Land prices are currently low enough to make multiple lot purchases more financially feasible, and 3. Since the area's median household income is well below the city average, these smaller homes are more affordable so local residents could stay in their neighborhood and escape the gentrification currently happening nearby. The Modern Trinity home is based on the regional Philadelphia Trinity House typology in which 3 single rooms are stacked vertically to create a house with a very small footprint. This design requires 3 adjacent vacant lots, but rather than 3 homes lined up along the street front, units are repositioned along the northern boundary with large south-facing windows overlooking a large communal green space formed from the other 2 lots. The southern orientation ensures all units have abundant sunlight for passive solar heating, daylighting, and PV power. Operable windows for cross ventilation and passive shading from overhanging balconies reinforce the sustainable design strategies.

KEYWORDS: urban, infill, housing, affordable, sustainable

INTRODUCTION

The numbers defining our current housing crisis are daunting. In 2020, 30% of all households had "unaffordable" rent or mortgage payments, defined as exceeding 30% of monthly household income...and more than 1 in 7 households paid over half of their income on housing (Habitat for Humanity 2023). There is a national shortage of 7.3 million affordable and available rental homes for extremely low-income renters (National Low Income Housing Coalition 2023). And on top of this, population demographics are changing with greater demand by the Missing Middle sector of people, who do not fit the typical family structure and make a decent income, yet still cannot find affordable housing (Parolek 2020). While this presents a high hurdle to clear, there is still an untapped abundance of vacant land in our cities with enormous potential to address this problem.

Rather than just replace the former cramped, dark row homes, this project proposes a new typology of smaller homes reoriented to provide greater access to sunlight, fresh air, and green space. Not every location is feasible for this approach, but the Lower North district of Philadelphia was used as a test site for several reasons. First, it contains an abundance of scattered, vacant pockets of property with at least 3 adjacent lots on north-south oriented streets, which are necessary for this design parti. Second, the land prices are currently low enough to make multiple lot purchases, and when combined with modular construction techniques, can make these homes financially feasible. And third, the area's median household income is well below the city average so many who cannot afford the new market-rate homes currently being built could more likely afford these smaller homes.

1.0 DESIGN CONCEPT BACKGROUND

This new typology of sustainable and affordable smaller homes that are reoriented on the site, springs from previous design research for the Side Yard House (SYH), a concept of a long thin house, similar to the Charleston House typology. Because it would be very difficult to understand the current research without this background, some of that earlier research is included here for reference and clarity, but this specific paper focuses specifically on new *urban infill* research conducted within the past year. Both the SYH and this new concept are repositioned along the north border of the lot to prevent shading by the neighboring home to the south, with abundant south-facing windows looking into a communal green space on the south side. (e.g. Figure 1) The broad, south facade of the home contains the vast majority of the glazing with minimal fenestration on the east, west and north sides. This ensures all units have abundant sunlight for passive solar heating, daylighting, and PV power, while maintaining a well-insulated envelope with only the necessary amount of poorly insulating glass surface. Operable windows for cross ventilation, passive shading from the overhanging balconies, and the green side yard, all help cool the building passively to minimize the need for mechanical air conditioning and increase overall energy efficiency and resiliency.

As a single-family detached house on a larger lot, the SYH worked very well on sites where an entire *block* was vacant, (as in the test city of Detroit). However, it did not adapt well as a smaller, more affordable home for tight urban infill sites, thus by limiting the potential application opportunities.

As the need for affordable housing is huge within these urban environments, this new phase of design research focused specifically on how the concept could be revised and applied to smaller homes on smaller infill lots within an existing block of row homes. Or rather, instead of a complete new set of dentures, just filling in the missing teeth. The passive energy strategies of the SYH transferred across to the new design but the scale, scope and size of the units were all completely revised downward to create smaller, more affordable, urban infill homes.

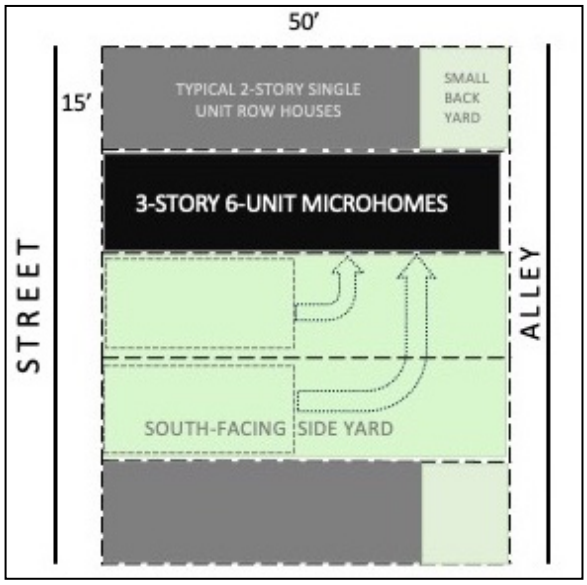


Figure 1: MT Concept Plan Diagram. Source: (Author 202

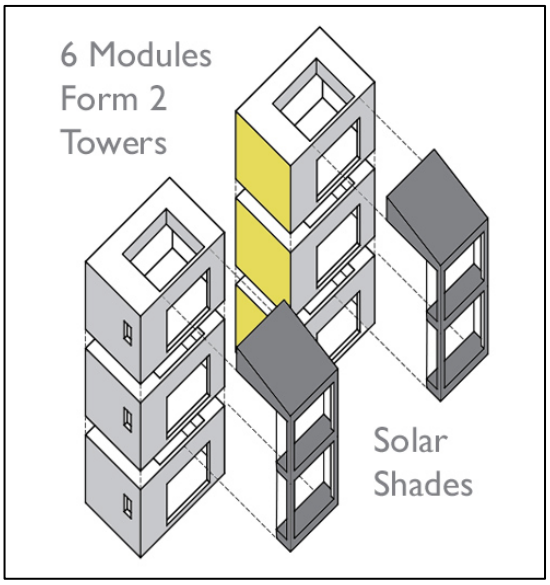


Figure 2: MT Concept Axonometric. Source: (Author 2023)

The concept for this new infill design combines the passive energy strategies from the Charleston typology with another traditional space-saving housing typology, Philadelphia Trinity House. The Trinity, also known as the "Father, Son and Holy Ghost" House, is a housing typology unique to Philadelphia in which 3 single rooms are stacked vertically and connected by a tight winding stair to create a house with a very small, space-saving footprint. (e.g. Figure 5) Kitchens are located on the ground level or basement, living areas on the middle floor, and a bedroom on the third. Originally, bathrooms were in backyard outhouses which makes incorporating them inside renovated versions more difficult. This new Modern Trinity (MT) typology updates the classic Trinity to improve on these issues while at the same time making the home more sustainable. (e.g. Figure 2) Like the SYH, units are still located along the northern lot line to maximize southern exposure, but because of the much narrower 15' urban sites, 3 adjacent lots are required to create a large enough site. Two adjacent lots would not allow enough space on the south side for winter sunlight to reach overtop of the neighboring building or create a large enough side yard to be functional. However, even on a smaller site, the MT's smaller footprint and vertical orientation uses considerably less land per unit and therefore allows for 2-9 units (depending on lot depth) per 3-lot site instead of one single, larger, detached SYH home. Rather than lining 3 Trinities up along the street front as was traditionally done, multiple units are repositioned along the northern lot boundary like the SYH with large south-facing windows that access the large communal green space. (e.g. Figure 3 & 4) Three single-floor flats stacked on top of each other, as has been traditionally done, would create the same amount of floor area but the units would not have equal access to light, air, and green space. The unit on the bottom would get less sun and air flow but would have access to the yard. Upper units would get more light and air but would have no access to the green space. With the Trinity design each unit get equal access to all.

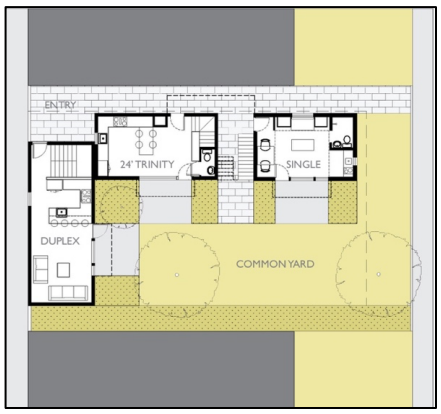


Figure 3: Floor Plan. Source: (Author 2023).

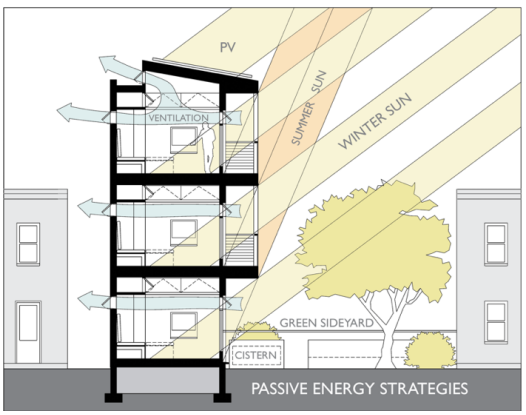


Figure 4: Section with Passive Energy. Source: (Author2023)

2.0 LOCATION RESEARCH

The previous research into side-yard housing utilized larger and more contiguous sites with little to no existing buildings. Grey, Green and Brownfield sites were used in suburban locations and entire vacant *blocks* with medium size lots for urban sites (as in Detroit). This degree of open land allowed the freedom to insert and repeat the housing pattern across a large area so an entire neighborhood of sustainable middle-income homes could be built on these sites. However, this approach had a couple flaws. The homes were too large to be affordable to lower-Income buyers and, with large blocks of open land becoming rarer, it did not work well on the available smaller infill sites. This severely limited the potential sites, so for this design to be truly feasible on a larger scale, it needed to be able to adapt to urban infill conditions and become much more affordable to lower income buyers.

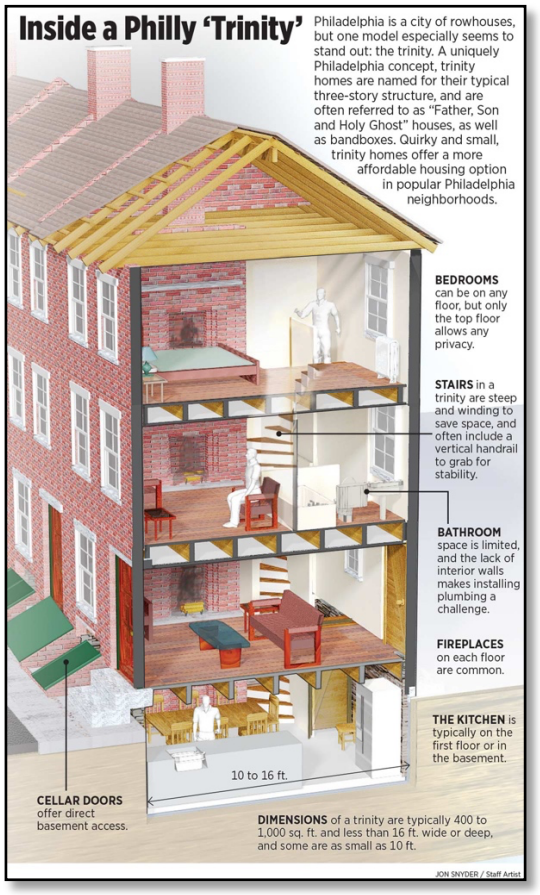


Figure 5: Trinity. Source: (Jon Snyder, Phila. Inquirer 2017)



Figure 6: 3-Lot Sites. Source: (Google Maps & Author 2023)

Since this concept requires a potentially rare site made up of 3 adjacent lots on north-south oriented streets, it was important to first identify a location with a sufficient number of useable sites to confirm the project's viability. The Lower North District just north of center city Philadelphia is an ideal location for several reasons. First, the 6-square-mile district contains approximately 34,000 rowhome lots of which roughly 8,000 are vacant, or almost 25% (Philadelphia Planning Commission 2014). (e.g. Figure 6) Second, the Lower North sits in a prime location just north of downtown with excellent public amenities like transportation, commercial zones and institutional facilities, (Temple University sits squarely in the center of the district). Yet, the majority of the area has not yet been overtaken by gentrification and new development (as is happening in neighboring districts). And third, land prices are currently low enough to keep land costs for multiple lot purchases low enough to make the project financially feasible. This is important because the area's median household income is well below the city average, so many who cannot afford the market rate homes currently being built around them could afford these smaller homes and not be forced out of their neighborhood.

Even though there are over 8000 vacant lots in the district, this design concept requires 3 *adjacent* lots on north-south running streets, so it was critical to ensure there were enough sites that met this condition. So, a GIS (Geographic Information System) study was conducted to identify the total quantity of 3-lot sites along with the lot depth dimensions. The results, shown in the map below, revealed that there are just over 800 3-lot sites on N-S streets in the workable range of 40' to 100'+ in depth. (e.g. Figure 7) Using some simple math, with about 800 potential sites, a conservative average of 3.5 units per site, and an average of 2 people per unit, it would be possible to house about 5,600 people in the Lower North using this design. These numbers suggest this approach is not limited to a few select sites but is applicable on a large scale in this district.

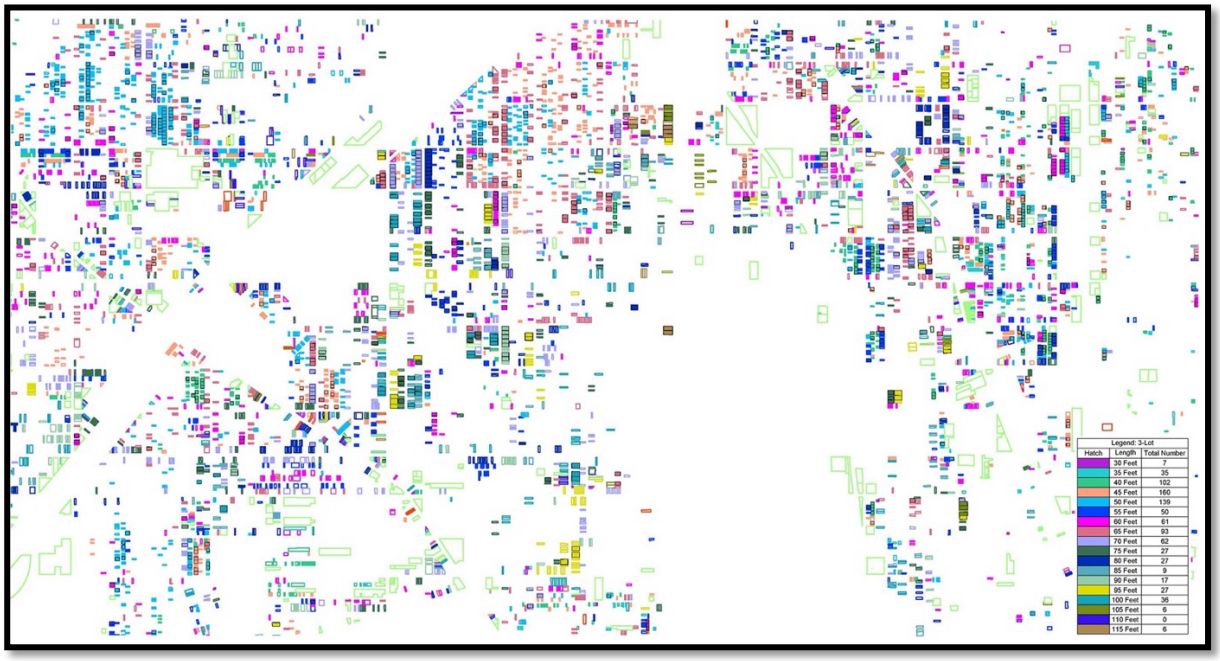


Figure 7: GIS Map of Vacant 3-Lot Sites in the Lower North District. Source: (Trisha Kawa 2023)

3.0 UNIT SIZE VARIATIONS

> Due to shifting household demographics and market interests, there is a tremendous mismatch between the available housing stock in the United States and the type of housing that people want and need.…The household and cultural demographics of the United States have shifted dramatically-nearly 30 percent of all households are now single person. By 2035, one in five Americans will be over the age of sixty-five, and households without children will make up 84 percent of change in households between 2015 and 2025. (Parolek 2020, 1-2)

Demographics of home buyers today have changed greatly from the average 4-person family of mother, father and two children. Non-traditional family structures now require a variety of housing options that are not readily available and/or affordable. Further, groups in the Missing Middle demographic such as aging parents, boomerang children, young couples and single parents often do not need, and cannot afford, the larger houses being built today. So, there is a need for a variety of smaller, lower-cost homes in a range of sizes. To address this, the Modern Trinity homes come in 4 different 3-story models. The smallest unit is a tiny 250 square feet single-story microhome for single residents that can be stacked 3 units high. While not a true Trinity by definition, it forms one while creating 3 units using the same volume of space. The slightly larger 3-story Trinities have an internal stair connecting cooking, living, and sleeping levels. These are geared towards couples and are available in 3 sizes with floor areas of 750, 900 or the largest at 1050 square feet that includes an additional bedroom. For deeper lots that come with corresponding higher land costs, a duplex model was developed to increase land use efficiency by maximizing the number of dwelling units per site. Below are further descriptions of each unit.

3.1 The microhome

These smallest units are single 20’ long modules that are stacked 3 units high (to form a Trinity) and are accessed by an external shared stair that can serve 3 or 6 units. They combine all functions in one space, similar to a Single Room Occupancy room or studio apartment, so are intended for a single person. Because of the small floor area, a space saving strategy is applied that borrows from airline overhead storage bins. A U-shaped space containing functional “wet” zones with storage bins above surrounds a taller central convertible living and sleeping space. They are by far the most affordable but have a limited audience due to their small size. The balconies used to provide passive shading also provide some exterior spatial relief to the upper units.

3.2 The trinities

The majority of the homes would be Trinities composed of 3 units stacked vertically connected by a private internal stair. They consist of a live-in kitchen/dining on the ground floor, living/work space on the second and sleeping/bath on the third. They come in 3 lengths of 20’, 24’ and 28’ (based on the 4’ module of construction materials to minimize cut-off waste) to adapt to site depth dimensions and buyers’ variable budgets. They are intended for a couple but the largest unit could accommodate a small child as well. Each unit has a patio and 2 balconies overlooking the green space.

3.3 The duplex

As lots slowly increase in their depth dimension, they cannot always accommodate another full unit length along the north lot line. So, to maximize the number of units per site, the Duplex is rotated 90 degrees and sited along the street front and if deep enough, along the back lot line as well, to fit in another unit. If this unit was made into a 3-story Trinity in this orientation, it would block too much south-east and south-west sunlight to the other units. So, it

is kept only 2 stories high to allow sun access while maintaining the street's urban wall and increase privacy from the sidewalk. It is the longest unit at 32' long so can accommodate all of the kitchen/dining/living functions on the ground floor and allows room for 2 bedrooms and bath on the second. The extra bedroom accommodates owners with children or live-in relatives. This unit does not face south so a skylight over the internal stair volume would be used to bring in natural sunlight, but the living spaces still face into the green garden.

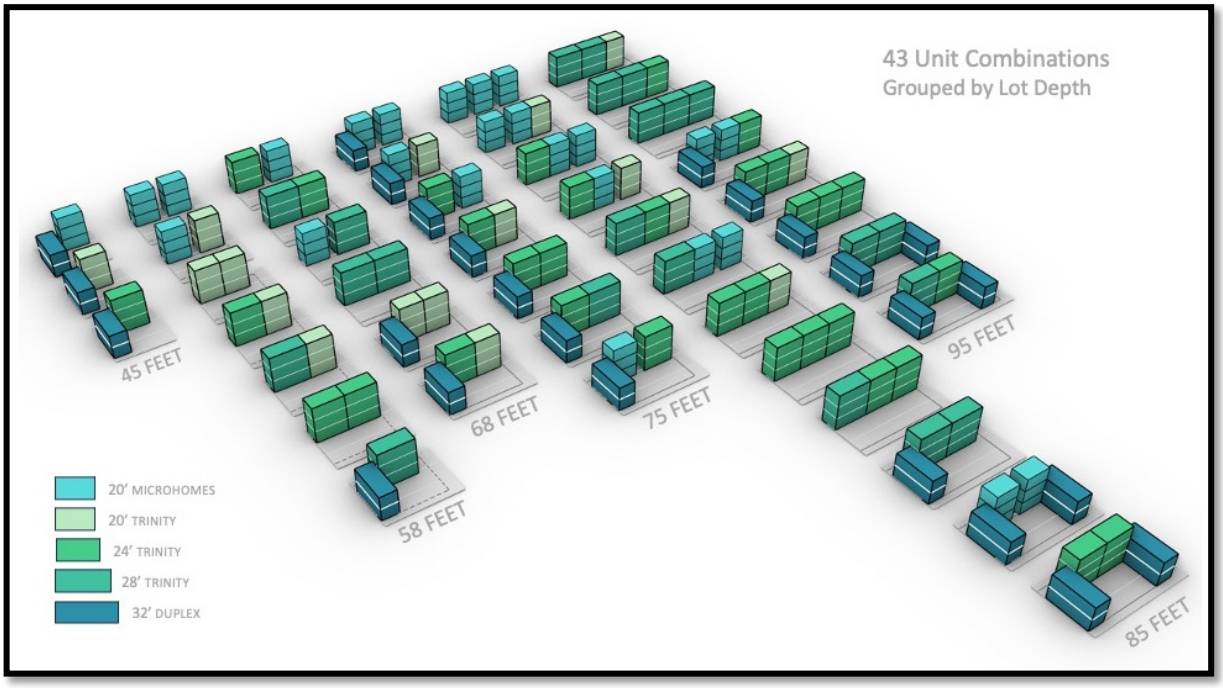


Figure 8: Unit Combination Options. Source: (Trisha Kawa 2023)

As mentioned above, while collecting GIS research of vacant lots, it was noticed that while the width of the lots remained fairly constant, between 14 feet and 16 feet, the depth varied greatly with the vast majority ranging between 45 feet and 95 feet. As the lot depth determines how many units can fit, we tested the various unit combination options based on triple-lot depth and discovered 43 different arrangements were possible, from a minimum of 2 units to a maximum of 9 units per site. (e.g. Figure 8) This offers a great variety of options for accommodating diverse owner demographics. The multiple module combinations possible per site create a wide variety of units that can accommodate the range of diverse, non-traditional family structures required for missing middle housing. One owner could rent out entire property to separate residents. Or, with this range of units possible per site, a single family could own a building lot comprised of three or four units of various sizes in which their siblings, parents, and/or adult children could live together in support each other. Unused units could also be rented out as Accessory Dwelling Units to help defray the mortgage costs. As shown in the graphic above, there are multiple combinations possible to adapt to a variety of buyer demands.

4.0 AFFORDABLE MODULAR CONSTRUCTION

The Lower North District overall has a below-average income level so it is crucial to keep construction costs low to create as much access to housing as possible. There are several strategies used to promote low initial cost. First, the smaller than average size of the homes themselves translates directly to lower per-square-foot costs for all the units. Costs can be further reduced through the use of pre-manufactured, modular construction which costs an average of 10% to 20% less than stick built construction.

In 1969 the US federal government launched *Operation Breaththrough*, an initiative to produce more factory built houses, but it didn't work as today only 2 percent of single-family homes in the US are factory built (Appelbaum 2023). But builders are increasingly returning to the advantages of modular construction as construction costs keep skyrocketing. The Micro-Trinity flows the standard dimensioning of premanufactured construction. All modules are a nominal 12' wide to fit on a flatbed truck and the lengths are sized using the 4-foot module of standard construction materials to create unit lengths of 20', 24', 28' and 32' increments, with 2 of the smaller units being able to fit on a 53' flatbed truck.

While producing precise cost estimates would require further in-depth analysis, current pricing data was used to derive some rough home cost estimates. Current construction costs in Philadelphia average around $124 per square foot for very basic construction (Marshall 2024). As with all real estate, land costs vary per location. However, current asking prices in the LND for smaller vacant sites range from as low as $13K up to $50K for larger lots. Three adjacent lots added together would cost from $40K to $150K, but as larger lots hold more units, when divided by the units per site the average land cost per unit is roughly the same at about $20K (and less for the smaller microunits). Using the U.S. Health and Human Services latest 2023 Poverty Guidelines of $14,580 annual income for a single person and $19,720 for a couple, the Microhome is the only model affordable for the Extremely Low-Income bracket (Office of the Assistant Secretary for Planning and Evaluation 2023). However, based on the above

stated determination of affordability as no more than 30% of income spent on housing, the average household income required to purchase these homes indicates that most units fall within the range of the intended Low-Income and Missing Middle housing market. The chart below compares these estimates by unit type. (e.g. Table 1)

Table 1: Construction Cost Estimates. Source: (Author 2023)

Unit Type	Total Area	Construction at $124 psf[7]	Land Costs / Units / Site	Total Housing Costs	Monthly Mortgage, 6% APR	Annual Income Req'd @ 30%
20' Micro	260 sf	$32,240	$10,000	**$42, 240**	$253	**$10,100**
20' Trinity	780 sf	$96,720	$20,000	**$116,720**	$700	**$28,000**
24' Trinity	936 sf	$116,064	$20,000	**$136,064**	$815	**$32,600**
28' Trinity	1,092 sf	$135,408	$20,000	**$155,408**	$932	**$37, 280**
32' Duplex	832 sf	$103,168	$20,000	**$123,168**	$738	**$29,500**

Affordability is not only addressed as initial construction costs but is also considered with operating costs. Being able to afford to buy a house does not guarantee the ability to pay for its operation. To keep utility bills low, the units are designed to be well-insulated and sealed as close to Passive House standards as individual budgets allow. Plus, a photovoltaic system (potentially purchased using government subsidies) can even further reduce utility bills. The PV system and extra insulating materials needed would be rather minimal because of the small home size and shared walls/floors but would still increase initial construction costs by 5% or more. However, these costs would be tempered by the 10% - 20% saving from modular construction and somewhat cancel out each other. The SYH was tested with the Sefaira software program for thermal and daylighting efficiency and performed well. The Modern Trinity is currently starting testing.



Figure 9: Perspective Rendering of Modern Trinity Homes. Source: (Zach Winton 2023)

CONCLUSION

The southern orientation and 3 adjacent lot requirements of the Modern Trinity mean it is limited in its overall application. However, many US cities were laid out on a north-south grid and (shamefully) have a great deal of abandoned infill sites still available for development. The Lower North District of Philadelphia, as well as many neighborhoods in cities like Detroit, are prime locations for this type of project that can help to combat the lack of affordable housing while simultaneously fighting to preserve our planet.

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Spatiotemporal Assessment of Outdoor Thermal Comfort Regimes in Urban Plazas of Chicago

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ABSTRACT: Unique microclimates in urban plazas around tall buildings impact people's presence, which is driven by the Outdoor Thermal Comfort (OTC) levels. Increasing interest in OTC studies due to their significant contribution to the UN Sustainable Development Goal SDG11 has led to the development of advanced OTC indices. Urban designers and planners strive to gain knowledge in assessing their outdoor public space designs through these indices, thus understanding the impact of such developments on people's social lives. Microclimate CFD simulation is a popular method commonly employed on this topic. This study uses CFD simulation using ENVImet to model microclimates and OTC indices for five urban plazas in downtown Chicago with Dfa climate zone. The study adopts a spatiotemporal approach to assess three OTC indices, namely, Physiological Equivalent Temperature (PET), Standard Effective Temperature (SET*), and Universal Temperature Climate Index (UTCI). Using physiological thermal stress levels as a basis for comparison, the spatial approach involves the distribution of comfort regimes in the plazas, while the temporal approach uses the mean values of the OTC indices to address the research objectives, which are (a) comparing 'neutral' comfort regimes of PET, SET*, & UTCI during a peak lunch hour of the summer solstice day, (b) exploring spatial distribution of neutral regimes of these indices, (c) temporal analysis of PET thermal stress categories and microclimatic variables between 12-2 pm, and (d) spatiotemporal analysis of the same within and between the plazas. The findings show that SET* and UTCI lack granularity around neutral thermal stress regimes, unlike PET, which limits the understanding of finer thermal conditions that may exist in the plazas and could be critical in the success of the plaza. The other key findings of this study highlight the importance of the spatial distribution of thermal stresses in assessing the thermal conditions of an outdoor environment.

KEYWORDS: outdoor thermal comfort, microclimate, urban plazas, cfd, thermal stress

INTRODUCTION

Microclimate creates a thermal environment that impacts people's presence in outdoor public spaces (Tsitoura, Tsoutsos, and Daras 2014), thus contributing to the quality of life in cities, both from an economic and social viewpoint (Stathopoulos 2009). Humans perceive the thermal environment through thermal comfort. Outdoor Thermal Comfort (OTC) studies over the past few decades have gained momentum due to their direct contribution to the UN Sustainable Development Goal SDG11 (United Nations Department of Economic and Social Affairs 2023). Numerous OTC models and indices have been developed during this period. These studies are also critical to understanding human physiological thermal stress levels. Extremities in microclimates could increase stress levels, which are found to be hazardous to human health (Luber and McGeehin 2008). Hence, OTC indices and their associated thermal stresses become an important area of study for public space design. Recent interest in the OTC topic has led to many studies exploring the OTC models and their thermal perceptions, which are based on subjective models developed through people's perceptions of their comfort levels (Potchter et al. 2018; Cheung and Jim 2017). Thermal stresses and their comfort perceptions in certain models associated with a temperature range could provide a basis for comparison. The continuous surge in world population has led to an increase in tall urban scenarios in cities, which create unique microclimates. These climatic conditions impact the outdoor urban spaces in such cities. Architects and urban planners strive to gain knowledge in outdoor public space designs to ensure sustainable development. James Parakh, in his work, stresses the relationship between tall buildings and open spaces by stating-

> One of the key ways that tall buildings contribute to the public realm is by framing and creating open spaces at their base. (Parakh 2015).

Moreover, a lot of work has been done on OTC and outdoor public spaces in mid-rise urban conditions in temperate climate zones, unlike the case in US cities with tall buildings in the continental climate zone of the Koppen climate classification (Kumar and Sharma 2020; Khan, Azari, and Stephens 2020). One such case is Chicago city with its "Dfa" hot summer humid continental climate. The city of Chicago has a rich history of tall buildings. The definition of 'tall' is usually relative to the average building heights of the urban context as defined by the Council of Tall Buildings and Urban Habitat (CTBUH). Per this definition, a building with 150m and above height is considered a tall building in Chicago (CTBUH 2019). A comprehensive study on the public spaces around tall buildings in Chicago shows that out of 116 tall buildings (150m+ height), around 56 have public spaces at the ground level (Khan and Du 2020). Not all these spaces are successful or popular in terms of people's attendance. One of the likely reasons could be microclimates, which could be significantly different given their urban morphological conditions. This research is an effort to fill this knowledge gap in this area.

1.0 LITERATURE REVIEW

1.1. OTC indices and research question

OTC indices are a function of varied climatic factors that impact human behavior in outdoor spaces. These include temperature, humidity, solar radiation, and wind velocity. Studies show that perception of thermal environment, created by these microclimatic variables, also involve physiological and behavioral variables, namely metabolic rates and clothing levels respectively (Nikolopoulou and Steemers 2003; Chen and Ng 2012). The assessment of OTC perception has resulted in numerous indices. It ranges from simple models that were adapted from indoor thermal comfort models to advanced ones that include heat stress or energy balance models comprising of all the variables discussed earlier in this section. Some of the most commonly used indices are PET (Physiological equivalent temperature) by Hoppe in 1992 (Höppe 1999), SET* (Standard Effective Temperature) by Gagge et al. (Gagge, Fobelets, and Berglund 1986) and PMV (Predicted Mean Vote) by Fanger in 1972 (Fanger 1982) (Honjo 2009). However, the unit of PMV is an actual vote, unlike the rest, which uses temperature as a unit. Because of this, PMV is excluded from the discussion in this research. Nevertheless, the other three indices offer a high level of sophistication and have been compared in various studies through different lens (Zare et al. 2018; Potchter et al. 2018; Coccolo et al. 2016).

A comprehensive study of more than 160 OTC indices uses an evaluation score through six criteria namely comprehensiveness (number of variables), scope (range of environmental conditions), sophistication (conceptual merits), transparency (clarity in rationale), usability (application), and validity (reliability) to sort them for an easy use (de Freitas and Grigorieva 2017) (refer to Table 1). One of the criteria, which is the lowest for all the three indices, considers computational procedure, standard data, and easy output as a structure for evaluation. This research explores this criterion further within these models by applying the logic on five plazas in Dfa Climate zone city i.e. Chicago.

Table 1: Five assessment criteria to rate PET, SET*, UTCI. Source: (Extracted from the comprehensive list from (de Freitas and Grigorieva 2017))

Index	Comprehensiveness	Scope	Sophistication	Transparency	Usability	Validity	Total
PET	5	5	5	5	3	3	26
SET*	5	3	5	5	3	5	26
UTCI	5	5	5	5	3	4	27

Thermal perceptions defined through the human physiological stress levels of outdoor thermal conditions provide wholistic understanding of OTC indices. These stress levels are categorized using levels which are set in temperature units in certain indices namely PET, SET*, and UTCI. This study uses thermal stress as a basis of comparing the three indices. Several studies exist where thermal stress thresholds for different indices are documented and discussed at length (Coccolo et al. 2016; Zare et al. 2018). Table 2 is developed from these studies to reflect the stress levels, and threshold for the studies OTC indices.

Table 2: Thermal Stress Categories for PET, SET*, UTCI. Source: (Adopted from (Zare et al. 2018))

	PET (°C)	SET (°C)	UTCI (°C)
extreme cold	<4		<-40
very cold			-40 to -27
cold	4 to 8		-27 to -13
moderate cold	8 to 13	<17	-13 to 0
slight cold	13 to 18		0 to 9
comfortable (neutral)	18 to 23	17 to 30	9 to 26
slightly warm	23 to 29		
warm	29 to 35	30 to 34	26 to 32
hot	35 to 40	34 to 37	32 to 38
strong heat			38 to 46
very hot	>41	>37	> 46

1.2. CFD modeling of microclimates

The continued interest in microclimates and OTC research has increased the use of Computational Fluid Dynamics (CFD) simulation as a popular research methodology on this topic. One of the biggest advantage of this approach is the ease in controlling the outdoor environment which is dynamic and challenging in real life (Toparlar et al. 2015; 2017). Amongst various software, ENVImet provides a comprehensive package of tools to simulate and visualize meteorological data, urban environments, vegetation, and soil types. It also includes Biomet that computes OTC indices PET, SET*, UTCI and PMV for these environments (Bruse 2018). The possibility of finer grid resolutions have been explored in many OTC studies (Maleki et al. 2014; Reinhart, Dhariwal, and Gero 2017). Typical OTC studies using CFD simulation focus on the values of OTC indices and their alignment with the benchmarks set for the investigation. Limited work has been done on the frequency of spatial distribution of these values in space. This study explores the novel approach of spatiotemporal distribution of OTC values and their associated thermal stress levels to answer following research questions: (1) How do the three OTC indices (PET, SET* & UTCI) differ in five different Plazas of Chicago when assessed using their mean values at 12 pm on a summer solstice day?, (2) What is the spatial distribution of neutral regime for PET, SET*, & UTCI in each plaza? , (3) What is the trend observed

in microclimatic variables and PET thermal stresses when analyzed temporally during the mid-day break from 12pm to 2 pm?, and (4) What is the spatiotemporal distribution of PET thermal stress within and between the Plazas during this mid-day break?

2.0 RESEARCH METHODOLOGY

2.1. Study area

Five outdoor public plazas in downtown Chicago are considered for this research. These plazas are located in the urban blocks enclosed between W. Randolph, Clark, Dearborn, and W Jackson streets. Each plaza is at the ground level of an iconic tall building. These are 197.5m tall Rachard Daley Center (1965) housing (01) the Daley Plaza, 264.5 m tall Chase tower (1969) housing (02) the Chase Plaza, 173.9 m tall One South Dearborn (2005) housing (03) the Dearborn Plaza; and 171.3 m tall Kluczynski Federal center (1974) housing (04) the Federal NE (Northeast) Plaza and (05) Federal SW (Southwest) Plaza (refer to Figure 1). Other adjacent buildings around these plazas range from 15m to 100m.



Figure 1: Location of five plazas of Chicago. Source: (Author 2021)

2.2. Microclimate modelling using ENVImet.

The research methodology involves microclimate modeling using ENVI-met software to conduct simulations. The selected day for the simulation was June 21, a summer solstice in 2019. The total simulation time was set to three hours, with the initializing hour starting at 11 am. The context was modeled in ENVImet Monde World Editor using the Daley Center, Chicago coordinates. The digitized model used information from an open street map, Google views, and CTBUH skyscraper center. The vectorized model is then exported to a raster-based .INX file for simulation. Three spatial domains consisting of five plazas were exported from this model using settings shown in Table 3. Instead of nesting grids, the model was expanded by real grid cells. This paper uses an open lateral boundary condition (where grid values closest to the border are copied to the next ones in each time step) with Simple Forcing for temperature and relative humidity at an hourly interval. Other input parameters (listed in Table 4) are taken from the diurnal meteorological conditions collected from a nearby weather station located 325m from the Daley Plaza. The site roughness selected for the simulation is 0.1, representing dense urban conditions.

Table 3: Spatial domain settings for ENVImet simulations. Source: (Author 2024)

Model Geometry	model dimension (no. of grids)			grid cell sizes (m)			highest building in domain	3D model top height	min. distance between bldgs & model border
	x	y	z	dx	dy	dz	(m)	(m)	
Federal NE Plaza & Federal SW Plaza	96	105	100	4	4	4	178	400	18 grids
Chase Plaza & One S Dearborn Plaza	97	108	109	4	4	4	265	547	15 grids
Daley Plaza	95	107	105	4	4	4	230	463	13 grids

Table 4: Initial Meteorological conditions for simulations. Source: (Author 2024)

Initial Meteorological Conditions	
Wind Speed (m/s)	6.26
Wind Direction (Deg)	90 East
Roughness Length at Measurement Site	0.1
Minimum Temperature of Atmosphere (°C)	11.67
Maximum Temperature of Atmosphere (°C)	22.22
Minimum Relative Humidity (%)	43
Maximum Relative Humidity (%)	75

3.0 RESULTS

The data analysis uses a spatiotemporal approach to compare the three OTC models to derive the results. The temporal approach uses the mean values of the OTC index and its associated thermal stress categories, while the spatial approach uses a percentage of space under different stress categories as a metric for comparison. The three OTC models are compared using their thermal sensation thresholds for comfort conditions.

3.1. Comparative analysis of PET, SET*, & UTCI at 12 pm

Statistical test ANOVA (analysis of variation) single factor was performed for all the five plazas to analyze the difference between the means of PET, SET*, and UTCI values. The results revealed that there was a statistically significant difference in means of all the three indices in the listed plazas ($F(2, 510) = [132.9]$, $p < 0.05$) for Federal NE plaza; ($F(2, 231) = [21.1]$, $p < 0.05$) for Federal SW plaza; ($F(2, 357) = [38.6]$, $p < 0.05$) for Dearborn plaza; ($F(2, 1005) = [72.5]$, $p < 0.05$) for Chase plaza; and ($F(2, 1053) = [314.6]$, $p < 0.05$) for Daley plaza. The box plots comparisons in Figure 2 show the distribution of data used in these analyses for five plazas.

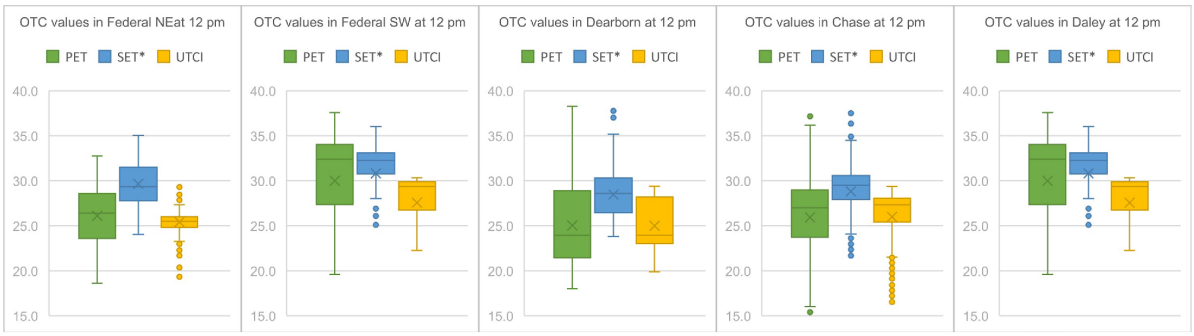


Figure 2: Box plots showing the PET, SET*, and UTCI in five plazas of Chicago. Source: (Author 2024)

The comparative analysis of the three OTC indices: PET, SET*, and UTCI mean values, and the corresponding thermal stress at 12 pm in the five plazas are presented in Table 2. It was found that the thermal conditions of Daley Plaza are under the neutral physiological thermal stress category for the three indices, whereas Federal SW Plaza is under the warm thermal stress category. This implies that Daley Plaza is likely to be the most preferred plaza in summer noon. Moreover, the high granularity in PET thermal stress categories creates a better understanding of thermal conditions in these plazas. For instance, the slightly warm conditions in Federal NE, Dearborn, and Chase Plaza help to distinguish them from others, unlike the case SET* or UTCI indices. However, this gravely impacts the spatial distribution of PET-neutral regimes in the plazas. Hence, for the sake of comparison, an "extended comfort sensation" is considered that increases the comfort thresholds to include neutral, slightly warm, and slightly cold categories for PET, which matches the thresholds of the next stress categories around neutral regimes for SET* & UTCI (refer to Table 5).

Table 5: Mean and standard deviation values of OTC indices PET, SET*, and UTCI and their corresponding thermal stress levels. Source: (Author 2024)

OTC indices at 12 pm		PET (°C)	Thermal stress	SET* (°C)	Thermal stress	UTCI (°C)	Thermal stress
Federal NE Plaza	Mean	26.2	slightly warm	29.8	neutral	25.6	neutral
	SD	3.2		2.7		1.6	
Federal SW Plaza	Mean	30.6	warm	31.5	warm	28.2	warm
	SD	4.6		2.3		2.4	
Dearborn Plaza	Mean	25.2	slightly warm	28.7	neutral	25.2	neutral
	SD	4.7		2.8		2.8	
Chase Plaza	Mean	26.0	slightly warm	28.9	neutral	26.0	neutral
	SD	4.5		2.9		3.1	
Daley Plaza	Mean	19.4	neutral	24.5	neutral	20.4	neutral
	SD	2.8		1.9		3.6	

3.2. Spatial distribution of neutral regime for PET, SET*, & UTCI at 12 pm

The comparative analysis of the PET, SET*, and UTCI neutral regime spatial distribution in the five plazas was initiated with ANOVA single factor test. The results demonstrated a statistically significant difference in the values of the five plazas with ($F(4, 10) = [4.4]$, $p = 0.03$). The comparison is further presented in Figure 3 charts. The top row shows the spatial distribution of neutral regime in the five plazas. Daley Plaza shows the highest distribution of for all the three indices. Moreover, the comparison within the groups shows PET has the lowest distribution for all five plazas which can be explained by its lower threshold values for this regime unlike the other two (refer to Table 1). This case is reversed when the comparison is made using the "extended comfort sensation" for these indices. PET demonstrates the highest spatial distribution amongst the three. These findings open a discussion on if an

intermediate stress category is required between neutral and warm stresses for SET* and UTCI, and neutral and moderate cold for SET*. It is recommended to have one since the results may not be indicative of its given cause and proposes conducting an onsite survey to confirm the thermal stress thresholds for each OTC index.

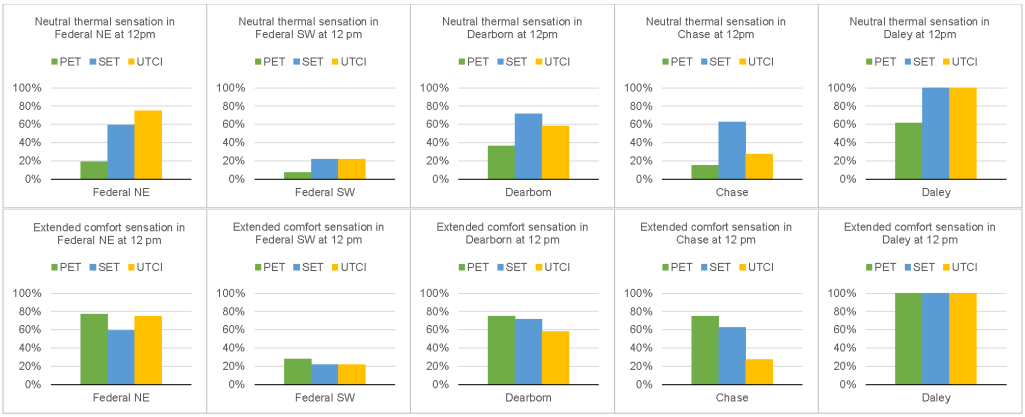


Figure 3: Spatial distribution of neutral regime (top row),and extended comfort regime (bottom row) of PET, SET*, and UTCI in five plazas of Chicago. Source: (Author 2024).

3.3. Temporal analysis of microclimatic variables and PET thermal stresses during mid-day break

A midday break with a 12 – 2 pm time block is considered for assessing thermal comfort variations and their corresponding thermal stresses. Table 6 presents the mean values for PET at 12 pm, 1 pm, and 2 pm for five plazas. It is found that PET thermal stress remains consistent during this period except for Federal NE and Federal SW plazas. The former gets warmer while the latter gets cooler at 2 pm. This could be further explained by the trend in microclimatic variables during this time block (refer to Figure 4). These variables, namely Temperature (°C), Mean Radiant Temperature (°C), Relative Humidity (%), and Wind Speed (m/s), are presented in Table 7. The data trend for Relative Humidity shows a decrease from 58% to 53% in the Federal NE Plaza and an increase from 54.1% to 58.1% in the Federal SW Plaza. The temperature trend is reversed, showing an increase from 16.4°C to 17.4°C in Federal NE Plaza and a decrease from 17.3°C to 16.4°C. The increasing MRT and the constant wind speed trends for both plazas do not seem to contribute to the change in the thermal stresses from 1 to 2 pm.

Table 6: Mean and standard deviation of PET and its corresponding thermal stress levels in five plazas. Source: (Author 2024)

	PET	12 pm	Thermal stress	1 pm	Thermal stress	2 pm	Thermal stress
Federal NE Plaza	Mean	26.2	slightly warm	26.2	slightly warm	29.6	warm
	SD	3.2		3.5		6.1	
Federal SW Plaza	Mean	30.6	warm	31.8	warm	25.7	slightly warm
	SD	4.6		4.9		5.2	
Dearborn Plaza	Mean	25.2	slightly warm	25.7	slightly warm	23.8	slightly warm
	SD	4.7		6.8		6.5	
Chase Plaza	Mean	26.0	slightly warm	27.3	slightly warm	26.9	slightly warm
	SD	4.5		4.6		5.6	
Daley Plaza	Mean	19.4	neutral	20.6	neutral	22.4	neutral
	SD	2.8		2.9		2.7	

Table 7: Mean and standard deviation values of microclimatic variables for five plazas. Source: (Author 2024)

		W (m/s)			RH (%)			MRT (°C)			T (°C)		
		12 pm	1 pm	2 pm	12 pm	1 pm	2 pm	12 pm	1 pm	2 pm	12 pm	1 pm	2 pm
Federal NE Plaza	Mean	0.9	0.9	0.9	58.0	55.9	53.8	48.3	47.4	52.6	16.4	16.9	17.4
	SD	0.8	0.8	0.8	0.2	0.2	0.3	6.8	8.3	11.6	0.1	0.1	0.1
Federal SW Plaza	Mean	0.6	0.6	0.6	54.1	56.0	58.1	42.9	55.4	54.0	17.3	16.9	16.4
	SD	0.2	0.2	0.2	0.1	0.1	0.1	8.9	8.1	7.8	0.0	0.0	0.0
Dearborn Plaza	Mean	1.1	1.1	1.1	53.8	55.9	57.9	41.7	46.7	47.9	17.3	16.9	16.4
	SD	1.0	0.9	0.9	0.2	0.1	0.1	9.9	10.0	9.4	0.0	0.0	0.0
Chase Plaza	Mean	1.0	1.0	1.0	53.8	55.9	57.9	52.3	54.0	49.3	17.7	17.5	17.1
	SD	0.7	0.7	0.7	0.2	0.2	0.2	10.6	7.4	8.8	0.8	1.1	1.3
Daley Plaza	Mean	3.4	3.4	3.4	53.5	55.6	57.8	58.7	54.0	51.2	17.5	17.0	16.5
	SD	0.7	0.7	0.7	0.3	0.3	0.3	8.1	8.8	8.4	0.1	0.1	0.1

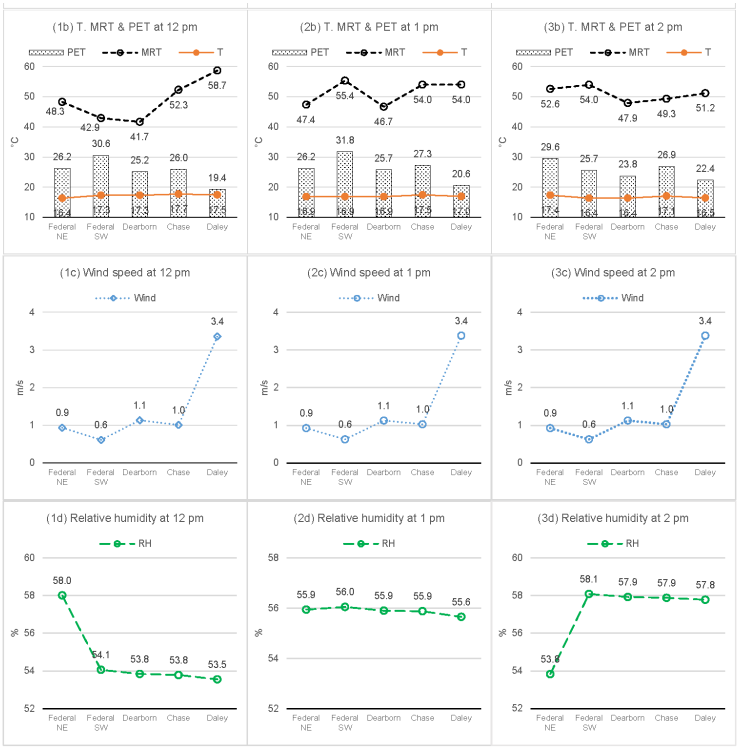


Figure 4: Microclimatic variables during mid-day break of a summer solstice in five plazas of Chicago. Source: (Author 2024).

3.4. Spatiotemporal distribution of PET thermal stress during mid-day break

A spatiotemporal distribution of PET thermal stress categories in five plazas provides insight into the relative frequencies of thermal stress data (a) within each plaza and (b) across five plazas for 12 pm, 1 pm, and 2 pm (refer to Figure 5). The results for Chase Plaza demonstrate the spatial distribution of five thermal stress categories for all three hours. The other Plazas showing similar patterns are Dearborn Plaza for 1 pm and 2 pm, and Federal NE/SW Plazas for 2 pm. Further, Dearborn at 1 pm and Federal NE at 2 pm show even distributions, suggesting the Plazas offer varied choices of thermal conditions for people. This also explains the shift in the average PET values and its corresponding thermal stress from 1 pm to 2 pm as discussed in the previous section (refer to Table 3). The pattern of Daley Plaza is unique when compared to the other plazas. It is the only plaza with the highest neutral thermal stress category, with 61% at 12 pm and 55% at 1 pm. This implies that the Plaza will be preferred by people during the summer afternoons.

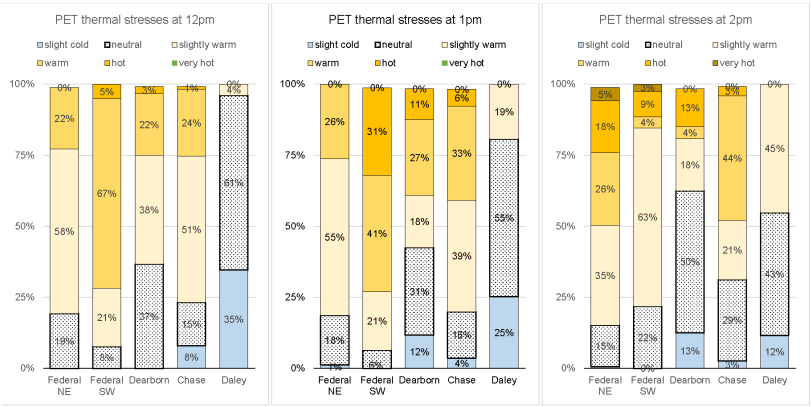


Figure 5: Spatiotemporal distribution of PET thermal stresses in five plazas of Chicago. Source: (Author 2024).

4.0 DISCUSSION

The paper presented a spatiotemporal comparative analysis of outdoor thermal comfort conditions using five plazas with different morphological conditions in Chicago. The findings show that three indices, namely PET, SET*, and UTCI, demonstrate different outputs exhibiting their limitations in thermal stress levels, which must be considered in future studies. These findings are further elaborated in the sections below.

The findings from a comparative analysis of PET, SET*, and UTCI in these plazas at noon of summer solstice day provide the expected mean values of OTC indices, which can be used in designing plazas in Chicago or cities with

Dfa climate region. The associated thermal stress with these values highlights a key limitation in SET* and UTCI in assessing the thermal conditions of a Plaza. The two indices lack granularity around neutral thermal stress regimes, unlike PET. This limits the understanding of finer thermal conditions that may exist in the plazas and could be critical in the success of the plaza. It becomes more decisive when multiple design elements contribute to the microclimates of a plaza.

The findings from the spatial distribution of the neutral regime and the extended comfort conditions provide further insight into this issue. The results could be misleading in this analysis since PET with finer thresholds will always show lower spatial distribution compared to SET* and UTCI. To make a fair argument, an "extended comfort condition" is considered, which aligns with the next thermal stress category common to all three indices. The results show that PET has the highest spatial distribution. Although the results are purely based on the simulations, it is recommended to conduct another study investigating people's behavior and their thermal perception through onsite surveys.

OTC thermal stresses and microclimatic variables in the five plazas are further explored temporally in a 12-2 pm mid-day break period using mean PET values and their corresponding thermal stress for each hour. The findings show a thermal stress category variation in Federal NE & SW plazas at 2 pm. This variation is also observed in the microclimatic variables namely Relative Humidity and Temperature. Further study is required to investigate the interrelationships between these variables and PET values. The other three plazas do not exhibit any change in their thermal stresses. However, the spatiotemporal analyses of all the plazas demonstrate interesting findings around their thermal condition assessments. The findings pose a question on whether assessing thermal comfort through mean values is an appropriate approach, given the fact that there exist other thermal stress categories that are not captured. Thus, the assessment does not provide a comprehensive view of the thermal conditions. For example, the temporal analysis using mean PET values shows a constant thermal stress category, "slightly warm" in Chase Plaza. But the spatiotemporal distribution at 2 pm shows that 44% of the plaza exhibits "warm" thermal stress category. The same is also true for Dearborn Plaza at 2 pm, where 50% of the plaza exhibits "neutral" thermal stress category. Hence, it is important to consider the spatial distribution of thermal conditions.

These analyses also open a discussion on including thermal stress(es) as one of the design criteria for outdoor environments. While it would be ideal to have plazas dominated by neutral thermal stress, it is often challenging to achieve this condition temporally due to the dynamic nature of the outdoor climatic environment. Even if it is achieved at a specific time of the day, the real question would be whether such an environment would be ideal for people with different social-cultural characteristics. For example, a recent study shows that thermal perceptions differ based on gender (Jin, Liu, and Kang 2020). Hence, creating micro-environments within plazas exhibiting microclimatic variations could be a better solution, giving people choices to either adopt or to embrace change to retain their comfort levels.

It is also important to highlight one limitation of this study. The findings from temporal analysis comparing differences in mean PET values between different time blocks are limited due to the smaller sample size of temporal data. For example, the results for Dearborn, Chase, and Daley Plazas do not show much variation during the simulated period. However, this could be different if a larger sample set was used. Hence, it is recommended to address the issue in future studies. Moreover, the study assumes that thermal stress identified in the three indices are the same; however, few studies show that thermal stresses depend on multiple factors, namely climatic, socio-cultural, and psychological factors impacting its assessment (Schweiker et al. 2018).

CONCLUSION

The paper presented a spatial and temporal approach to compare three OTC indices namely PET, SET* and UTCI. The study was conducted for Chicago with the Dfa climate zone in Koppen Climate Classification. The indices were studied for five plazas in downtown Chicago with tall building urban conditions. ENVImet – a CFD microclimate modeling tool was used as a research methodology to derive the data for findings. The results showed that that SET* and UTCI lack granularity around neutral thermal stress regimes, unlike PET. This limits the understanding of finer thermal conditions that may exist and could be critical to the success of the plaza. The other key findings of this study highlight the importance of spatial distribution of thermal stresses in assessing the thermal conditions of an outdoor environment. The significance of this research is towards creating well designed outdoor public spaces that contribute to sustainable communities and improved public health as outlined in the UN SDG-11.

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Under, On, And Around The Table: A Case Study On Designing For Food Equity And Climate Justice In Architectural Design Studios

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ABSTRACT: How do we teach thinking about systems in design studios? And, more importantly, how do we move systems beyond the building and into community relationships, environmental concerns, and social equity? Our food system is unbalanced and unjust; with the rising temperatures and climate crisis, our already uneven system is being pushed to its limits. This paper will be a case study centered around two fourth-year undergraduate studios. It will explore a pedagogical interdisciplinary approach to exploring the intersection of climate/environmental justice and food justice in the design studio. These studios will focus on three pedagogical approaches and themes: interdisciplinary studies, systems-level interventions, and climate realities. Through these three pedagogical approaches, students will develop an understanding of the building, not as an isolated formal exercise but as a contribution to existing communities. The key issues addressed are local food inequity, community, site, and environmental justice. These studio exercises build on ongoing university research exploring the intersection of urban research, pedagogy, and practice. Urban research has long been essential for understanding urban areas' challenges and opportunities. Still, the gap between academic research and practical implementation remains challenging, especially in design. We will discuss how studios could be used as public research infrastructures and leveraged as a design tool for bridging this gap.

KEYWORDS: Pedagogy, Food equity, Community design, Climate justice, Design studio

1.0 INTRODUCTION AND CONTEXT

In 1968, during the American Institute of Architects (AIA) annual meeting, civil rights leader Whitney M. Young Jr. gave a compelling Keynote speech demanding that architects not hide from societal issues behind the title of designer but instead use their expertise to create change toward a better society (Young Jr. 1968). With the growing set of “wicked problems” (Rittel 1973 160) surrounding environmental, political, social, and economic issues that impact the built environment, architecture students stand at the front lines. The architecture studio, usually the most significant course requirement within any curriculum, plays a crucial role in training our next generation of designers. We must equip our students to become problem solvers who seek to design for more just futures. It is critical that in our teaching, we present architecture as a part of a larger whole. Architecture does not occur in a vacuum; various factors, such as policy, funding, and access, among others, shape the built environment. As educators, we must center architectural practice around the community it serves and educate students that buildings are not isolated structures but are interconnected within larger systems.

Historically, design studios have been the foundation of architectural education; they carry the most credits and are often prioritized by professors and students (Dutton 1987, 16; Deamer 2020, 5; Malecha 1988, 124). Topics covered in studio classes can range from speculative briefs to design-build studios to comprehensive projects. Though we support all forms of studio briefs, studios should introduce students to larger thematic issues, whether it be issues of labor, climate change, or local community matters; studios bridge the gap between design education and problem-solving. As stated by Peggy Deamer,

> the failure of a studio to engage with the world is linked to a school’s failure to prepare an architect empowered professionally to serve society (Deamer 2020),

and within our department, we have emphasized the need to focus on the public This paper will explore a design studio with a pedagogical interdisciplinary approach at the intersection of climate/environmental justice and food justice. Building on the work of John Dewey, a prominent education scholar who advocated for “learning through experience” and practical engagement in the real world (Dewey 1916), this studio allowed students to investigate these issues and ground their projects by applying their designs in a real neighborhood.

1.1 Context

Kean University and the foundations for this course are grounded in New Jersey. New Jersey, commonly referred to as “the Garden State,” boasts agriculture as its third largest industry. Yet, it has identified over 50 communities currently considered food deserts across the state. The United States Department of Agriculture (USDA) defines a food desert as an area with a minimum 20% poverty rate or, if located within an urban area, the closest grocery

store is over a mile away from at least 33% of the population (Dutko et al. 2012). New Jersey established the Food Desert Relief Act (FDRA) in 2021 and created a Food Equity officer position at the state level as part of its food access initiative. Part of this process was to create a food desert definition alongside the USDA's definition that reflects the reality of its communities. Focusing on factors such as walkability, food swamps, income relative to cost of living ratios, and percentage of households with internet access, the NJ FDRA expands the definition of food deserts within its community. With these new initiatives, the FDRA directs the state's Economic Development Authority investment of over

> $40 million per year for six years in tax credits, grants, loans, and technical assistance to increase access to nutritious foods and develop new approaches to alleviate food deserts (NJDEA 2022).

This has led to significant policy incentives, and food justice advocates eager to identify how to increase access to healthy food.

Alongside governmental and state-funded initiatives within New Jersey to expand food security, the state also has robust grassroots food equity non-profits such as Interfaith Neighbors, New Jersey Food Democracy Collaborative, among others. As a part of the course, we introduced students to these non-profit organizations through a tour of Kula Urban Farms and a presentation about the current food system by a member of Interfaith Neighbors. In that talk, students learned not only about issues of New Jersey at large but also how funding is distributed between these systems, how climate change affects farmers, and the need to create robust networks between farms, food pantries, and markets. What was key for us when introducing the subject of food access and equity within the studio was to introduce students to the grassroots organizations that are experts in the field and are leading the way. The New Jersey Food Democracy Collaborative developed a roadmap for food system resilience outlining the interconnected systems of environmental justice, health equity, and climate resilience, which we used as a guide in developing the studio brief (Cava et al. 2022).

Food access issues are not isolated to New Jersey or our campus; the World Health Organization has recognized the need for access to nutritious food as a critical factor of the built environment for health, well-being, and quality of life. Under Sustainable Development Goal 2, the United Nations also calls to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (United Nations 2023). Even on the smaller scale of the college campus, a 2019/2020 federal study by the National Postsecondary Student Aid Study (NPSAS) has shown that 22.6% of undergraduate students experience low food security, while 11.9% experience marginal food insecurity. These numbers are more than double the number of American households experiencing food insecurity (McKibben et al. 2023). When selecting a site for the studio brief, we chose a site within a 10-minute walk from campus. Right around the campus is a food desert, listed in the New Jersey Food Desert Community Designation Methodology report as one of the top 25 food deserts in the state. Students had to consider the site as an intersection of two communities: the city and their college campus.

2.0 FRAMEWORK

Building beyond the atelier studio model, where students share their ideas in a workshop setting, required expanding the studio past its six credits and using adjacent seminar and core classes to reinforce thematic threads. By creating connections between the studio and its adjacent courses, students could use systems thinking and explore the intersectionality of the issues presented. They were challenged to develop critical awareness in their coursework. Inspired by the work of Paolo Freire in developing "critical consciousness," students were encouraged to center their own lived experiences within their designs and research. Freire explains the concept of critical consciousness as having the capacity to intervene in that reality in order to change it (Freire 2005). Integrating real social issues into the studio allows the students to explore how design interventions can support social, economic, and environmental goals in addition to the architecture. Taking cues from architectural scholar and educator Dr. Sharon E. Sutton, we strongly agree that design studios should support *critical placemaking* within a community. While this semester did not have a community partner, the studios explored ideas of critical placemaking through local design interventions. Critical placemaking refers to the "participatory process of transforming racialized, under-resourced, and politically disenfranchised surroundings" (Sutton 2023 13). We designed our studios as an extension of a growing public research infrastructure within our institution. This studio, alongside the institutional interest in urban and local matters, can be a critical design tool for cultivating connections between academia, community, and practice. To create these connections, our studio brief was organized around three focus areas: Interdisciplinary Studies, Systems-level interventions, and Climate Realities.

2.1 Interdisciplinary studies

Beyond architecture, students had to think through an interdisciplinary lens to explore food studies, environmental justice, public health, and building systems and integrate these elements into their studio design projects. "Cooking as inquiry," as described in the essay by Jennifer Brady, is a technique that adds

> layers to the typically disembodied practices of social research that have long overlooked the body and the mundane rituals of foodmaking as sites of knowledge (Brady 2011 322).

Using this food studies technique in the studio, students explore food as material by drawing the ground, exploring it as an ingredient, and how we eat together shapes a space. With an emphasis on commensality, food is presented as a necessity and a cultural binding agent, bringing and strengthening communities through eating together. In introducing the overlap between environmental justice, climate realities, and the built environment's impact on public health, students were challenged to expand how they think about their designs as part of a larger ecosystem, not as a single piece of architecture. This meant they had to view their project from a historical, anthropological, sociological, and architectural perspective.

2.2 Systems-level interventions

As part of the studio, students interacted with local food organizations such as Kula Urban Farms and the New Jersey Food Democracy Collaborative to develop an understanding of the scope of food inequity. Using drawing as a driving force, students represented food as material while using collage, mapping, diagrams, and analysis. The act of drawing acts as a way to understand and visualize the intersectional nature of the systems of a regenerative economy, focusing on the intersection between embodied energy through a study of mass timber and the act of embodying the meals we consume. One system-level intervention our students explored was urban agriculture, which includes “cultivation, processing, and distribution of agricultural products in urban areas” (Dutko et al. 2012). In Beyond the Kale, Cohen references how, in addition to food production, urban agriculture can also be a means for cultivating social or environmental change in communities (Reynolds, Cohen 2016). In bridging connections between how food production can occur within and around existing buildings, students were required to understand building systems and explore innovative ways of integrating systems with ways of supporting the cultivation of food and community.

2.3 Climate realities

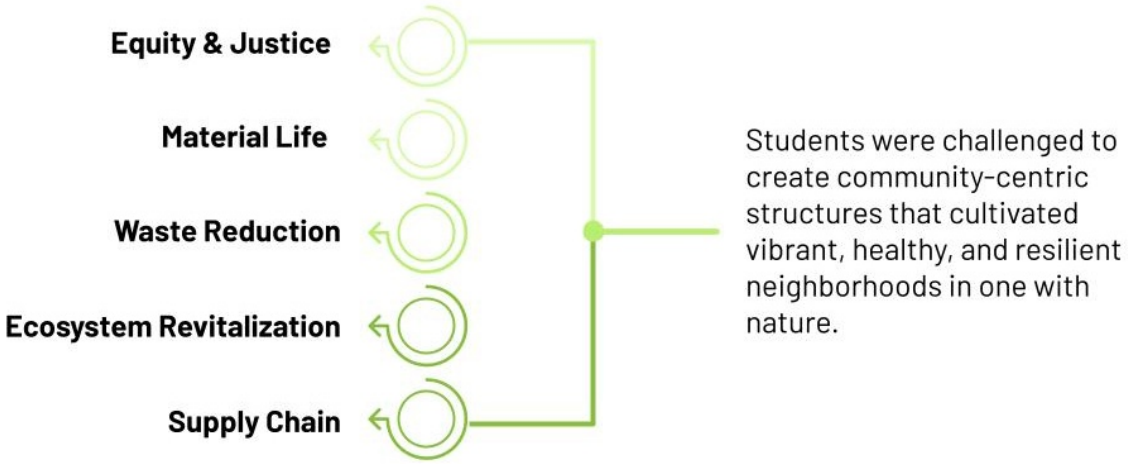


Figure 1: Diagram describing the multiple components inside the theme of climate realities. Source: (Author 2023)

This studio introduced sustainability as part of circular or regenerative principles. By embracing climate realities as a foundation of design education, we ensure that the next generation of architects can understand how the design of buildings impacts both natural and built spaces. By exploring concepts of equity and justice, waste reduction, ecosystem revitalization, material life, and supply chain, students were challenged to create community-centric structures that cultivated vibrant, healthy, and resilient neighborhoods in one with nature. Designers play a key role in determining how buildings generate and consume energy. Efficient building envelopes, onsite/renewable energy, and innovative water and waste management strategies can all contribute to a building that responds to climate action goals. Decarbonization requires us to consider the entire lifecycle of systems and shift from an extractive to a regenerative construction model. Cities are increasingly looking toward mass timber construction as one of the methods for achieving these goals. When ethically harvested, mass timber can efficiently “store carbon and offset lifecycle impacts” (Kuitennin et al., 2022). Climate realities extend beyond the sciences to the people; achieving climate justice requires a shift in social priorities, norms, and behaviors (Cruz 2023).

Through these three pedagogical approaches, students developed an understanding of the building, not as an isolated formal exercise but as a contribution to existing communities. Local food inequity, community, site, and environmental justice were among the critical issues addressed. These studio exercises build on ongoing university research exploring the intersection of urban research, pedagogy, and practice. Urban research has long been essential for understanding urban areas' challenges and opportunities. Still, the gap between academic research and practical implementation remains challenging, especially in design.

3.0 HOW THE STUDIOS RAN

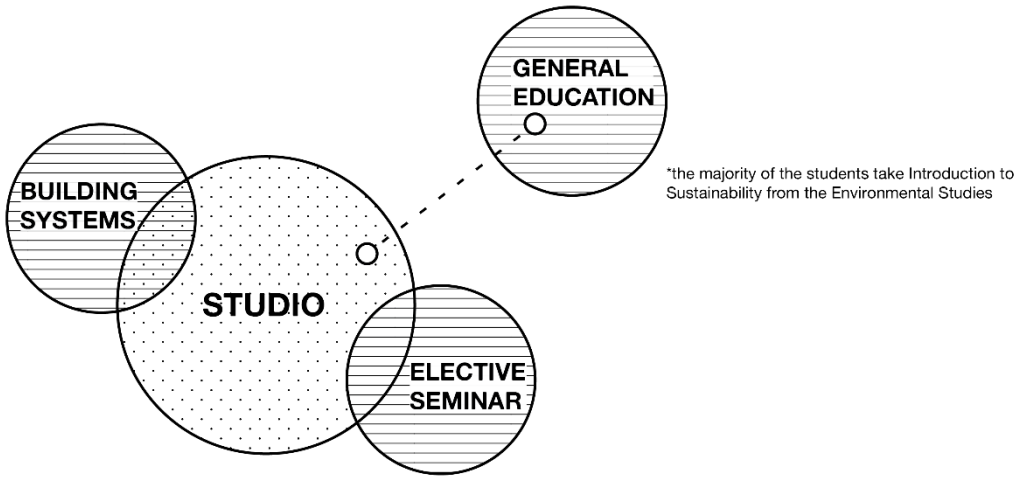


Figure 2: Course diagram describing the connections between the courses. Source: (Author 2023)

"Under, On, and Around the Table: Designing for Food Equity" was a coordinated fourth-year studio that tackled a food hub program and was coordinated with its adjacent courses, Building Systems I (BSI), and the elective seminars. This case study not only focuses on the studio itself but also its relationship with the adjacent courses. The intention behind aligning and coordinating adjacent courses with the studio prompt of food equity was to provide students with a series of different viewpoints as they worked on developing their designs. Students could select from one of four thematic seminars; topics explored ranged from food colonization to urban studies.

The four seminar focuses were:

- *Waste Practices* was a seminar that dealt with waste issues from multiple aspects, such as health, labor, politics, and climate change. Focusing on the social problems around waste production and how we envision waste as a culture, the seminar emphasized how waste could be recontextualized in architectural design.
- *Food Landscapes* focused on how the history of colonization and the built environment are inherently intertwined with food production and access. Through this historical perspective, students were asked to trace the lineage of food production, agriculture, and markets through the urban environment, beginning with Columbus' arrival to current movements in food equity and access.
- *Community Energies* focused on community-centered approaches around energy, urban design, equity, and power. The seminar explored how communities are impacted by policies and regulations of the built environment and the energy dynamics of transportation, infrastructure, and resource distribution, as well as green and public spaces on neighborhoods and public health.
- *Faceted Urbanism* focused on the formal aspect of cities ranging from squares, parks, neighborhood fabric, etc. Using both Western and Non-Western architectural precedents, the course expanded the students' knowledge of urban environments through a cross-cultural perspective that emphasized the social, cultural, and environmental aspects of the built environment.

Though students in each studio were a part of different seminar sections, we discovered that students began to share information from their respective seminars with their classmates and introduce those concepts within their studio projects. For example, a student in the *Community Energies* seminar incorporated water from a nearby river into her project and was inspired by an indigenous method of growing called *chinampas,* or floating gardens, that they had learned in the seminar. Another student in the *Waste Practices* seminar became interested in composting and food waste and changed the programming of their project to focus on it. By having diverse yet thematically linked seminars that students took alongside their studio and building system courses, students could make broader connections regarding their studio design projects around food equity and designing a food hub for their local community.

For the design studio portion, there were a total of four sections. All sections had an overarching brief about food equity, site research, sustainable architecture, and its correlation to the facade and structural design, which would be further developed in their Building Systems I course. All four sections were given autonomy under the umbrella syllabus, creating four perspectives focused on food equity. Each section could tailor their brief to include more growing spaces, market spaces, or other programs that fit their overall pedagogical intentions. One section focused on non-human food production and designing spaces for them, another on permaculture, and the other two on food systems and food as a material. The latter two sections are the focus of this case study and will be referred to as Section 01 and Section 02. As part of the studio, all sections had the same site and were introduced to food equity issues in New Jersey by meeting with Kula Urban Farms, a local urban farm in Asbury Park that is part of a larger non-profit organization called Interfaith Neighbors.

Section 01 began the semester studying and exploring food systems by having students select a specific vegetable or fruit and research its history, cultivation, and how it ends up on our table. With an emphasis on understanding who the stakeholders are throughout the entire process, including production, processing, distribution, and consumption, students were asked to analyze through a series of mapping exercises how these ingredients end up in our home critically. Students explored the food around them alongside their broader food systems research. They visited the apple orchard and vegetable garden on campus to understand different types of growing spaces, from hydroponics to more traditional forms of cultivation. With their food systems research and exposure to local growing spaces and conditions, students conducted site research focused on the climate conditions and how that would affect the overall design of the structure and the programmatic growing spaces.

Section 02 focuses on food as a material. Based on the methodology laid out by Jennifer Brady in her essay, "Cooking as Inquiry: A Method to Stir Up Prevailing Ways of Knowing Food, Body, and Identity," students were asked to recontextualize their relationship with food (Brady 2011). Their first exercise, As It Grows, had students select a vegetable or fruit actively growing in New Jersey. Once selected, they had to get the ingredients and study their texture, pattern, and tactile experience. By understanding the sensory information of the ingredient, they then drew the ingredient from roots to the sky, using only black and white patterns to get a layered and textured drawing. Following the initial drawing, their next exercise, When We Cook, asked students to make a dish from their ingredients and replicate it in the drawing. Through the act of cooking or designing a dish, students had the opportunity to consider how their ingredient is part of a dish and how it transformed. The last exercise, When We Dine, asked students to explore the spatial relationship between dining and commensality. Using the drawings from their previous exercise, students, with tables around the studio, were asked to rethink how we dine together and what it means to share a meal together. Based on these organizations, inspired by the diagrams and work of Teddy Cruz and Fonna Forman's book *Spatializing Justice*, students created their own building blocks based on food equity and commensality (Cruz, Forman, 2023). These exercises asked students to recontextualize their relationship to food and understand it as a potential material.

For both sections 01 and 02, students did site research on the climatic conditions on the site. Our site and the surrounding area suffer from flooding, which has worsened as climate change progresses. These conditions are experienced throughout the state of New Jersey. Alongside their climate research, students looked into the affordability and access to fresh food in the area, denoting that there was only one small grocery store within a 10-minute walk, and their prices were considerably higher than larger grocery stores for the same or slightly worse quality food. Students also noted that the site and area around it is a food swamp, full of unhealthy food options like fast-food restaurants and convenience stores. These were compiled into climate, food, and site research booklets. Students in both sections also developed a precedent booklet for their entire studio. These precedents were a mixture of food hub buildings and mass timber construction. As part of the booklet and precedent research, students had to programmatically and structurally analyze their precedents.

4.0 ASSESSMENT

In both sections, students took an exceptional interest in food research and understanding stakeholders, food as material, food access issues, and the area's climatic conditions. Though we ran a few mass timber lectures, had the BSI faculty join us for midreview, informal desk critiques, and finals reviews, and asked students to analyze and draw details of their mass timber precedents, some students struggled to take their abstract ideas of food and give them tectonic clarity. In its coordination, we realized that since students take their first Building System courses during this studio, they have yet to be adequately exposed to structure and tectonics. To alleviate this condition in future studios, we will need to run specific structural and tectonic exercises so students have a more robust understanding before they start designing. They could take the analysis of the mass timber precedents further and apply elements of their structure, such as CLT, glulam post and beam, and other systems, directly to their project to explore the spatial implications of their design process.

Due to this, the translation between early food research and final production needs further development with more specific exercises to guide students. Though students earnestly took to the earlier assignments and exercises, when asked to produce a structure and building for the studio, they defaulted to traditional design methods instead of investigating how their food systems and food as material research could lead them to new design forms. Those who took more of an interdisciplinary and community-focused approach when developing their building projects could create layered and complex projects that showed an understanding of what a food hub could be a community building and had structural and tectonic clarity. Below are three projects that exemplify the project's goals and deal with food equity, mass timber construction, and climate resiliency issues.

Section 01 - Alexa Acuna's project "Juxtaposed Flows" inspired by the spatial openness of Thorncrown Chapel by Fay Jones, was developed by examining the circulation of the overlapping communities on the site to create an open food experience and community gathering space. Focused on sustainable self-resilience, the project's use of hydroponics is intended to provide fresh food for the community.

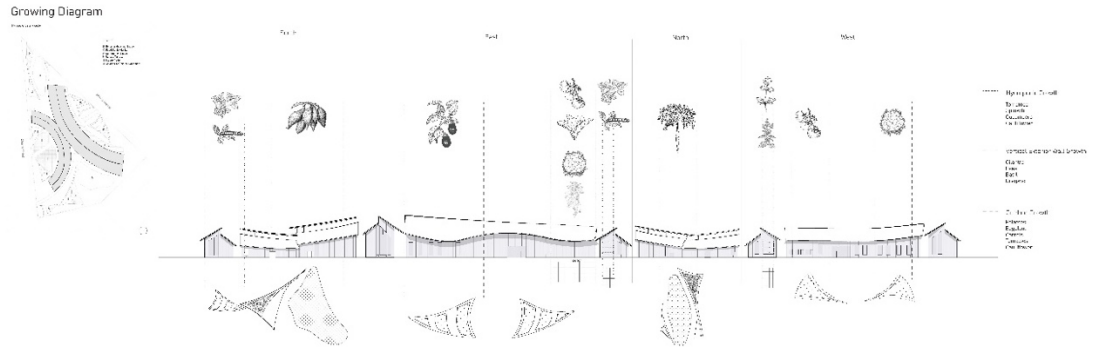


Figure 3: Growing Diagram of "Juxtaposed Flows." Source: (Author 2023)

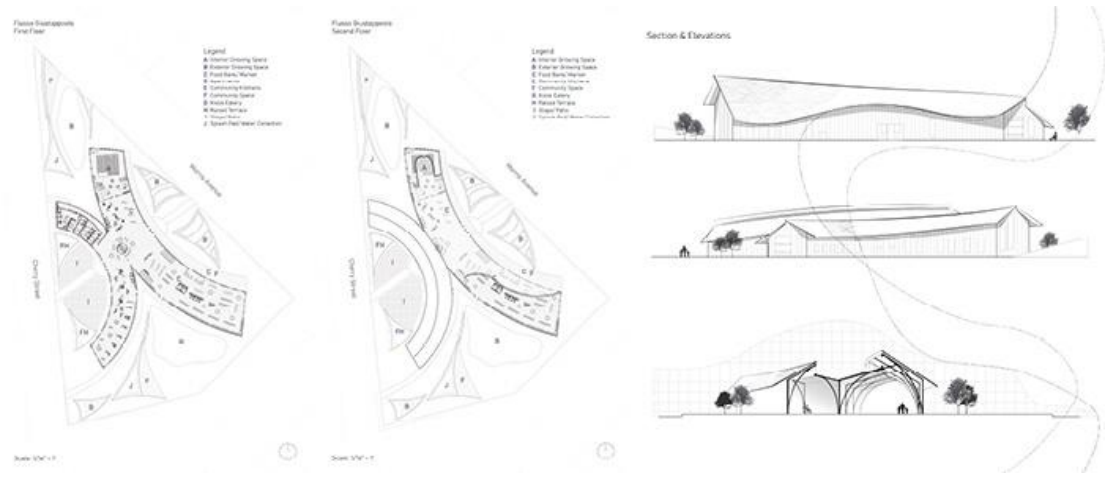


Figure 4: Floor Plans (left), Elevations, and Section (right) of "Juxtaposed Flows." Source: (Author 2023)

Section 02 - Kamila Diaz Calderon's project was focused on creating a food hub that provided educational possibilities to the local elementary school nearby, as well as providing more considerable resources the community could need, such as a medical clinic, commercial kitchens for local business owners, offices for immigration lawyers, indoor/outdoor growing, and indoor/outdoor classroom spaces. The large mass timber grid creates a shaded outdoor space for the project while the volumes break that grid.

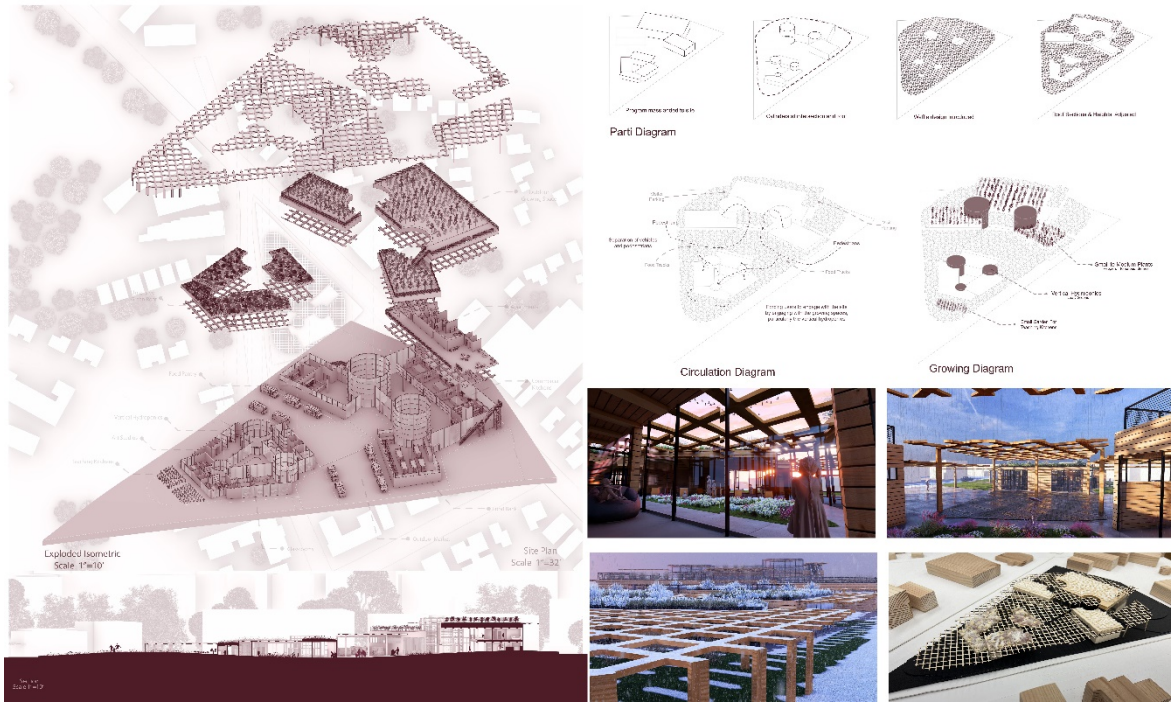


Figure 5: Images from Kamila Diaz Calderon's project. Exploded axonometric and section (left), diagrams (top right), and interior renderings and model photo (bottom right). Source: (Author 2023)

Section 02 - Christian Garganta's project was focused on creating a community commons; his project elevates the building and terrain to create a flood-resistant structure. On the edges of the site, Christian's project focuses on exterior growing spaces that can provide erosion support for the soil, and in its interior courtyard, there are educational spaces for the school nearby. The indoor spaces comprise indoor growing areas, classrooms, market spaces, and a commercial kitchen for local business owners.



Figure 06: Images from Christian Garganta's project. Rendered section perspective (top), growing diagram (bottom left), site plan (bottom middle), and interior rendering (bottom right). Source: (Author 2023)

CONCLUSIONS

Overall, the studio accomplished what it set out to do. As we plan for future iterations of this studio, one thing became clear - we need to develop stronger community connections with an active plan earlier. This studio is a core course with four sections, and each section has around fourteen students; we need to choreograph how students interact with non-profit organizations without becoming a burden to them while also accomplishing all the curricular needs of the semester. These complex studios tackle tectonics, social issues, and community impact in architectural design, and they need to be part of the core curriculum courses instead of peripheral option studios. Through this case study and studio, we were able to make connections within New Jersey's food systems that will aid us in providing those opportunities for future studios. At the end of the semester, students understood the role of food access within their community and how architecture and the built environment contribute to inequities. Though not all students grasp the translation between food research, site, and designing a building, we believe that by emphasizing the building blocks in Teddy Cruz and Fonna Forman's *Spatializing Justice* and Dr. Sharon E. Sutton's *Pedagogy of the Beloved Commons*, we can create a series of exercises to guide students through the process without being formally prescriptive for future iterations of the course.

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‘Resilience in Bamboo’

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ABSTRACT: A number of zero-carbon prefabricated bamboo buildings were built engaging marginalized communities in a few places in South Asia. This action-research was conducted by teachers and students of architecture who designed and built sustainable structures made of local materials such as bamboo, straw, rope and mud. The prototype design was revised, whenever needed, according to the climate, topography, landscape, materials as well as the traditional wisdom of the local tropical context. The building is significantly cost effective, especially in rural areas since it uses indigenous materials and local labor. The prototype structure using treated bamboo and a special rope-knotting system originally went through shaking table and wind tunnel tests by the prototype designer. The multi-use structures, now a year old, are weathering quite well. Short-term temperature readings of outdoor and indoor of some of these structures were collected to study the thermal performance in summer, and the indoors were found to be more comfortable than the outdoors.

The fact that most of the participants are women in both the students and community members prove the ability and confidence of women in building industry, which also addresses sustainable development goals.

The prefabricated bamboo structures have been particularly impactful in disaster-prone areas, serving as disaster rehabilitation buildings. After a devastating flood, over 2,000 of these buildings were constructed in a city, showcasing their value in disaster resilience. The project also allowed students and academics to directly apply classroom knowledge through hands-on building experiences.

The paper thus focuses on the major contributions of this action-research on constructing sustainable buildings addressing climate change, disaster resilience, involvement of marginalized communities especially women, and the knowledge dissemination in the academia.

KEYWORDS: sustainability, zero-carbon building, community participation, disaster rehabilitation building

INTRODUCTION

Traditional architecture ensures new changes and adopts well being for the dwellers through understanding of the environment and the human responsive systems (Doza and Ema 2019). In recent years, the global discourse on sustainable architecture has made an important shift towards innovative and eco-friendly solutions that address both environmental challenges and social inequities (Asefi and Afzali 2016). Against this backdrop, a transformative initiative was tried in various regions of South Asia, where a series of zero-carbon prefabricated bamboo buildings were constructed. This action-research endeavor, led by a group of dedicated academics, sought to engage marginalized communities, revolutionize sustainable construction practices, and contribute to broader societal goals.



Figure 1: Bamboo in Resilience. Source: (Ryan 2023)

1.0 BACKGROUND

1.1 Overview of the zero-carbon prefabricated bamboo buildings

The zero-carbon prefabricated bamboo buildings are examples of resilience, embodying a transformative approach to sustainable construction in the face of environmental challengesSurma (Salma 2022). Rooted in resilience, these structures leverage bamboo, straw, rope, and mud to create easily adaptable buildings. The design and the materials and methods of construction along with the learning from the traditional wisdom, make the buildings withstand the demands of various contexts. This adaptability also reinforces their capacity to serve diverse communities. The innovative structural elements, including treated bamboo and specialized rope-knotting system are the two important aspects of the resilience of the building. Rigorous testing of the prototype through shaking table and wind tunnel experiments ensured their durability and ability to withstand disasters to a great extent, contributing to their stability in the face of potential challenges. This emphasis on structural integrity aligns with the broader concept of resilience, creating buildings that can endure unforeseen circumstances and stand as symbols of sustainable longevity (Ben-Alon 2020). In disaster-prone regions, these prefabricated bamboo buildings emerge as resilient solutions with their modular and prefabricated design. Made of easily transportable bamboo panels, they facilitate swift assembly, enabling rapid response in the aftermath of natural disasters. The scalability of these structures has been demonstrated in the construction of thousands of buildings following devastating floods, showcasing their immediate applicability in crisis situations and underscoring their vital role in disaster resilience (Vengala and Raghunath 2020). In the aftermath of devastating monsoon rains and flooding in Pakistan, architect Yasmeen Lari led a humanitarian response to provide relief to the affected communities. Teaming up with INTBAU Pakistan and the Heritage Foundation, Lari initiated the construction of 1,000 prefabricated emergency shelters in severely impacted regions. These shelters, based on Lari's design known as the Lari Octa Green (LOG), were originally conceived after the 2015 Hindu Kush earthquake. Initially serving as emergency relief, some shelters now integrate adobe wall insulation, transitioning into a permanent housing solution for underserved communities in Sindh, addressing both immediate and long-term needs (Ahmed 2023). The commitment to resilience extends beyond the physical structures to encompass the empowerment of local communities. Through inclusive practices that actively involve women in teacher, student and community members, these projects address broader sustainability goals, fostering a sense of ownership and self-sufficiency within communities. A key goal of this action research was to empower women in marginalized communities in terms of building disaster rehabilitation buildings. The zero-carbon prefabricated bamboo buildings not only embody resilience in their design and construction but also contribute to the resilience and well-being of the communities they serve.

1.2. Engagement with marginalized communities

Engagement with marginalized communities expresses commitment to social equity and community empowerment. In various projects, such as the construction of zero-carbon prefabricated bamboo buildings, this engagement involves active collaboration among female members of the academia as well as marginalized communities. By placing an emphasis on inclusivity, the initiative ensures that the expertise of marginalized individuals are incorporated, fostering a sense of agency and community-driven development (Nurdiah and Anik 2020). Notably in this project, the deliberate inclusion of women in teacher, student and the local community breaks gender barriers, demonstrating the transformative impact of gender-inclusive practices. This engagement extends beyond the immediate project, promoting knowledge exchange and capacity building, creating a reciprocal learning environment. Ultimately, the engagement with marginalized communities serves as a catalyst for social change, economic empowerment, and the cultivation of sustainable, resilient communities.



Figure 2: Discussion and interactive session with community members. Source: (Authors 2023)

2.0 OBJECTIVE OF THE ACTION RESEARCH

The action research on zero-carbon prefabricated bamboo buildings is guided by a few objectives:

- Advancing Sustainable Construction Practices
- Empowering Marginalized Communities, Especially Women Members.
- Enhancing Disaster Resilience
- Knowledge Dissemination and Academic Integration

3.0 SUSTAINABLE BUILDING CONSTRUCTIONS: SITE AND LOCATION

The initiative was based on a zero-carbon bamboo building project of the Department of Architecture, SoAD, BRAC University Bangladesh, Heritage Foundation Pakistan, and The British Council UK under a gender grant of the British Council. A total of 25 institutions in Bangladesh, Pakistan, UK, Italy, USA and India took part. A 3-day workshop was held and screened live on various online platforms in several countries in early 2022 when the participants consisting of women students, graduates of architecture and women members of marginalized communities built the bamboo structures simultaneously in those countries. The selected volunteer students from Bangladesh and Pakistan later joined their British counterparts to build the bamboo structures in London and Bristol, UK in May 2022. The events thus showcased and encouraged women in the design and construction of prefabricated bamboo buildings which can be used as regular houses or a disaster rehabilitation structure. Among others, the following organizations were collaborated with the Bangladesh segment of the project:
Inside Bangladesh:

- Department of Architecture, School of Architecture and Design, BRAC University, Dhaka
- Department of Architecture, Leading University, Sylhet
- Architecture Department, Premier University, Chattogram
- CoCreation.Architects, Jhenaidah
- Institute of Architects Bangladesh, IAB.
- Paraa, Dhaka
- Shailan School, Dhamrai, Dhaka
- The Chakma Royal Family, Rangamati

Outside Bangladesh:

- The Department of Architecture and Planning, Indian Institute of Technology (IIT), Roorkee, Uttarakhand, India
- Department of Landscape Architecture, College of Agricultural Sciences and Natural Resources, Texas Tech University, Lubbock, Texas, USA
- The International Network for Traditional Building, Architecture & Urbanism (INTBAU), Pakistan & UK



Figure 3: Site & Location inside Bangladesh and outside of Bangladesh. Source: (Authors 2023)

3.0 METHODOLOGY

This action-research project involved the design and construction of zero-carbon prefabricated bamboo buildings in various rural areas of South Asia, engaging marginalized communities, particularly women. The methodology included collaborative efforts by architecture teachers and students who utilized local materials such as bamboo, straw, rope, and mud to build sustainable structures. Prototypes were rigorously tested and designs were adapted based on climate, topography, landscape, materials, and traditional wisdom. The project incorporated hands-on collaborative design talks and practical workshops to involve students and community members directly in the construction process. Short-term temperature readings were collected to assess thermal performance, and the structures were monitored over a year for durability. The prefabricated bamboo panels, designed for easy transport and assembly, were used effectively in disaster-prone areas for rehabilitation purposes, with over 2,000 buildings constructed post-flood. This research demonstrated the capability and confidence of women in the building industry and contributed to sustainable development goals, integrating practical knowledge into academic curricula and highlighting the role of sustainable architecture in disaster resilience and climate change mitigation.

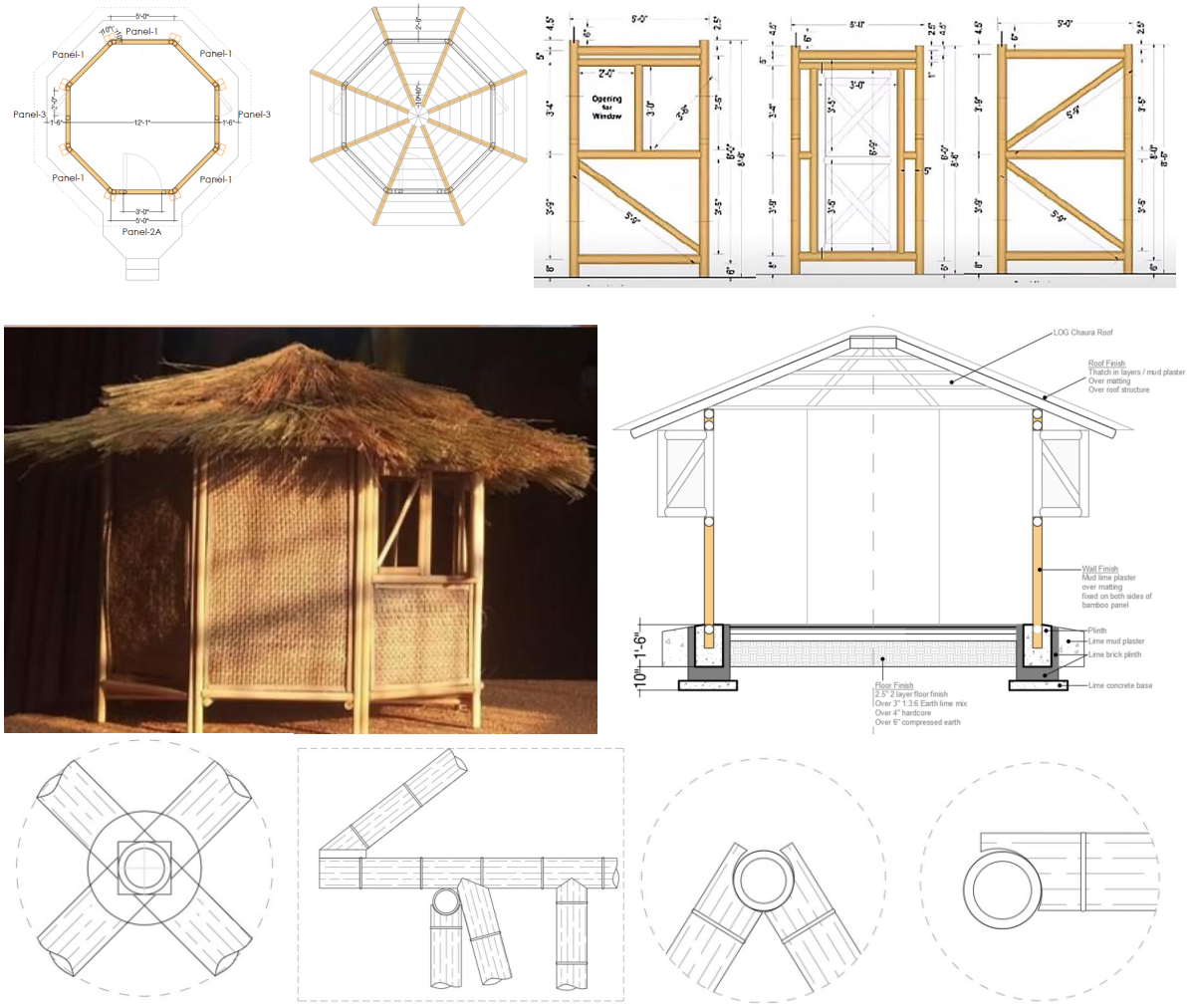


Figure 4: Plan, Elevation, Model, Section & Details of the prototype Zero Carbon Bamboo Building. Source: (Ahmed 2023 and Author 2022)



Figure 5: Workshop and bamboo treatment. Source: (Authors 2022)

4.0 COST EFFECTIVENESS AND SUSTAINABILITY

The zero-carbon prefabricated bamboo buildings showcase a blend of cost-effectiveness and sustainability, particularly in rural South Asian communities. The cost-effectiveness is rooted in the use of indigenous materials like bamboo, straw, rope, and mud, as well as the utilization of local labor. This not only reduces construction expenses but also stimulates local economies, aligning with sustainable development goals. The involvement of academics, students, and community members in the design and construction phases adds value by combining traditional wisdom with modern architectural insights, optimizing cost efficiency.



Figure 6: Zero carbon bamboo building construction. Source: (Authors 2022)

5.0 THERMAL PERFORMANCE AND COMFORT

The thermal performance and comfort levels of the zero-carbon prefabricated bamboo buildings are critical aspects that contribute to their overall sustainability and suitability for the local climate. The buildings, constructed with a focus on utilizing indigenous materials like bamboo, straw, rope, and mud, undergo a design adaptation befitting to the varying climate, topography, and landscape of the tropical context. Short-term temperature readings collected from both outdoor and indoor spaces of a few structures in the warm-humid Bangladesh reveal a noteworthy aspect - the indoors are found to be more comfortable than the outdoors, indicating a positive impact on occupant comfort. This finding underscores the success of the design in creating living spaces that are thermally comfortable, likely attributed to the choice of materials and the appropriate design revisions based on local conditions and expertise.

The use of treated bamboo, straw roof with extended eaves for sun and rain protection, mud floors, mat walls and awning windows allowing ventilation contribute to the positive thermal performance of the buildings. These features keep the indoor temperatures lower than outdoor temperatures. The buildings' ability to provide a comfortable indoor environment in the challenging tropical climate shows the effectiveness of the design strategies employed. And these zero carbon buildings are big energy savers. This emphasis on positive thermal performance enhances the livability of these structures, and also aligns with broader sustainability goals. By creating indoor spaces that are more comfortable than the outdoor environment, the buildings reduce the reliance on external cooling systems, contributing to energy efficiency and environmental conservation.

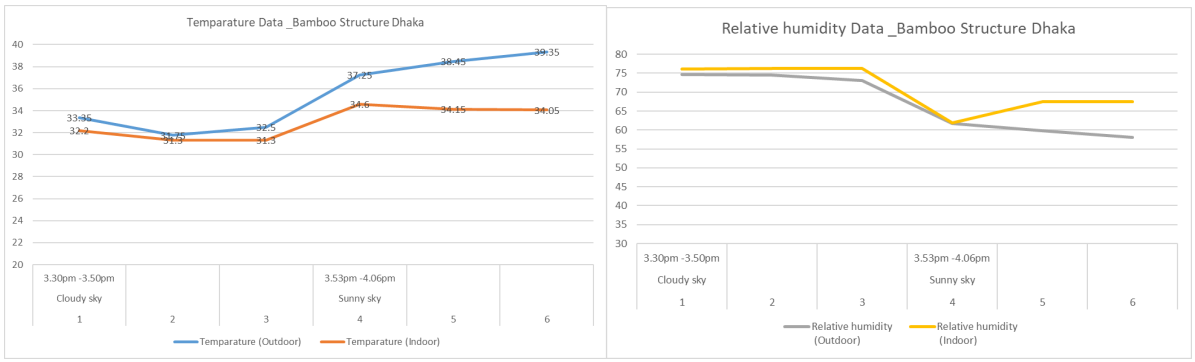


Figure 7: Thermal performance and comfort of the zero-carbon prefabricated bamboo building Dhaka. Source: (Authors 2023)

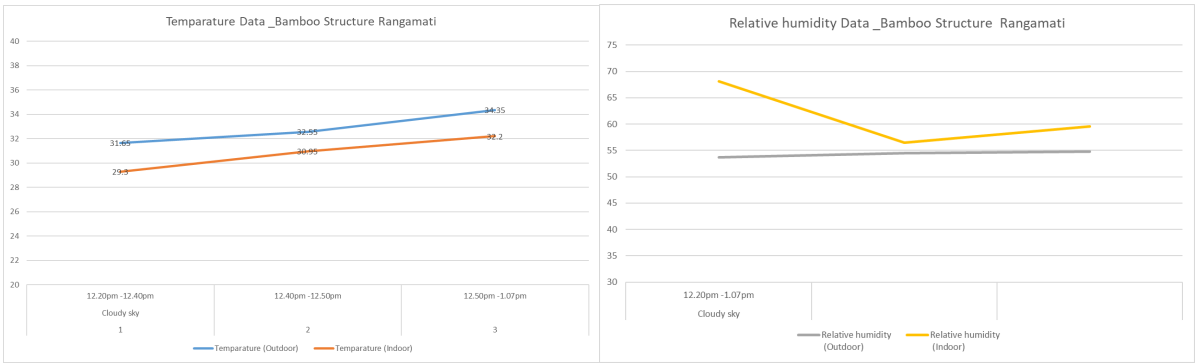


Figure 8: Thermal performance and comfort of the zero-carbon prefabricated bamboo building Rangamati. Source: (Authors 2023)

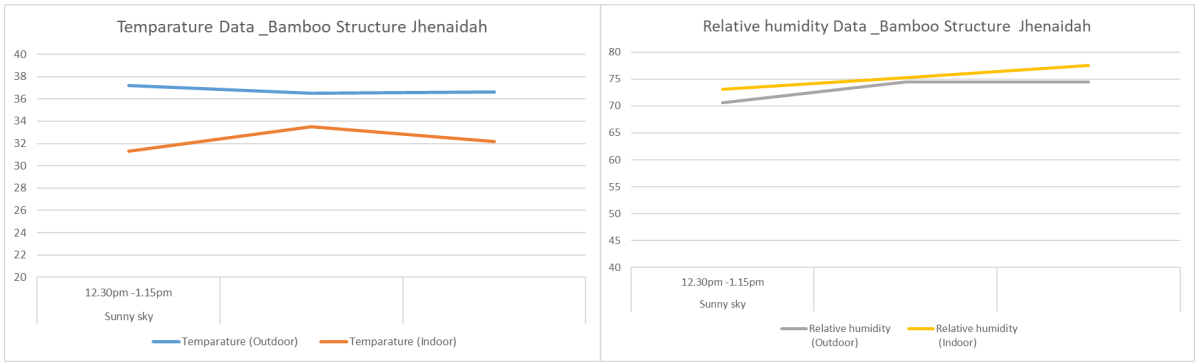


Figure 9: Thermal performance and comfort of the zero-carbon prefabricated bamboo building Jhenaidah. Source: (Authors 2023)

In summary, the thermal performance of the zero-carbon prefabricated bamboo buildings resulting in better comfort indoors that are shown in these charts add to their success. The integration of sustainable materials, careful design considerations, and the adaptability to local conditions collectively contribute to creating living spaces that are not only environmentally conscious but also prioritize the well-being and comfort of their occupants.

6.0 EMPOWERING WOMEN IN THE BUILDING INDUSTRY

The involvement of women in the construction of zero carbon bamboo buildings represents a significant stride towards gender empowerment and equality. The fact that most participants, both among students and community members, are women is a powerful evidence of their ability and confidence in the building sector. This engagement not only breaks traditional gender norms but also addresses broader sustainable development goals by promoting inclusivity and diversity within the industry. Empowering women in the building industry involves providing them with opportunities for skill development, hands-on experience, and leadership roles. In the context of the zero-carbon prefabricated bamboo buildings, women actively participated in designing and constructing sustainable structures using local materials such as bamboo, straw, rope, and mud. This hands-on involvement not only imparts practical skills but also instills a sense of confidence and ownership in women, challenging stereotypes about their roles in traditionally male-dominated fields.



Figure 10: Women in the construction of zero carbon bamboo building. Source: (Author 2023)

Moreover, the engagement of women in the construction process goes beyond the immediate project, contributing to their economic empowerment. By participating in the creation of sustainable buildings, women become active contributors to their communities' development, fostering a sense of self-sufficiency and independence.

The impact of this endeavor extends to the broader narrative of gender equality, demonstrating that women, especially of the marginalized communities, can excel in technical and hands-on professions. This not only transforms perceptions within the local communities but also serves as a model for sustainable development initiatives globally, highlighting the importance of gender inclusivity in various sectors.

7.0 DISASTER RESILIENCE



Figure 11: Zero carbon prefabricated bamboo buildings. Source: (Author 2023)

This building so far has been constructed in many places of South Asia. A great example of this is the building of about 2000 such rehabilitation homes in areas in Pakistan that were devastated by recent floods. As mentioned earlier, the prefabrication of panels made it easier to make the panels in a safe place and then transporting those to the flood affected areas where the buildings were erected at a great speed. In this way it was possible to build a large number of houses in the affected areas in a short time. It has been also seen that well-treated bamboo can withstand floods and heavy downpours. Also, the raised plinths are giving protection against flooding.

8.0 ACADEMIC IMPACT

The zero carbon prefabricated bamboo building's contribution to knowledge dissemination, hands-on learning, and the integration of practical insights into academic settings is noteworthy. The engagement of academics and students in the action-research project creates a dynamic bridge between theory and real-world application.

The involvement of teachers and students of architecture in designing and constructing sustainable structures using local materials such as bamboo, straw, rope, and mud is a hands-on learning experience that enriches academia. This practical engagement not only imparts valuable skills but also fosters a holistic approach to education by integrating traditional wisdom with modern architectural insights. The direct input of knowledge gained through hands-on construction in classrooms enhances the academic curriculum. The experiences from the project become a valuable source of real-world examples, case studies, and best practices. This direct transfer of knowledge ensures that academic institutions stay current with sustainable construction practices and align their teachings with practical industry applications. Furthermore, the academic impact extends beyond the immediate project, as insights gained from the action-research are likely to contribute to academic publications, research papers, and conference presentations. The collaboration between academics and the community creates a reciprocal learning environment where both parties benefit from each other's expertise and experiences. The participants also gain from the cultural understanding and enrichment.

In essence, the academic impact of the project lies in its ability to bridge the gap between theoretical knowledge and practical application. It promotes experiential learning, contributes to the enrichment of academic curricula, and ensures that academia plays a vital role in advancing sustainable building practices, climate change mitigation, and disaster resilience. The project's academic impact is a testament to the value of hands-on, community-engaged research in shaping the future of sustainable architecture and construction education.

CONCLUSION

In conclusion, the zero-carbon prefabricated bamboo building project stands as a beacon of innovation, sustainability, and community engagement. The multifaceted approach, involving academics, students, and marginalized communities, has yielded tangible benefits that extend beyond the immediate construction of sustainable structures. The success of the project lies in its ability to address key challenges such as climate change, disaster resilience, and gender inclusivity in the building industry. The cost-effective nature of the building, utilizing indigenous materials and local labor, not only makes them economically viable but also contributes to the economic empowerment of the communities involved. The thermal performance of the structures, demonstrated by short-term temperature readings, underscore their adaptability to local climates and their capability to enhance the well-being of occupants. The active participation of women, both among students and community members, challenges gender norms and fosters empowerment in the building industry. This inclusive model not only contributes to sustainable development goals but also serves as a testament to the ability and confidence of women in traditionally male-dominated fields. The disaster resilience of the specially designed prefabricated bamboo buildings, exemplified by their successful use as disaster rehabilitation structures, showcases their pivotal role in enhancing community resilience. The scalability, mobility, and durability of the structures make them invaluable assets in disaster-prone regions, providing swift and effective housing solutions. From an academic standpoint, the project's impact is evident in the hands-on learning experiences, knowledge dissemination, and the integration of practical insights into classrooms. The collaboration between academia and the community creates a synergistic learning environment that enriches both theoretical understanding and real-world application. The zero-carbon prefabricated bamboo building project represents a holistic and impactful approach to sustainable construction. Its contributions to economic development, gender empowerment, disaster resilience, and academic enrichment make it a model for sustainable development initiatives worldwide. It becomes evident that this action-research has not only constructed sustainable buildings but has also laid the foundation for resilient communities and a more inclusive, sustainable future.

ACKNOWLEDGEMENTS

Heartfelt gratitude is extended to the students, faculties, and community members whose active participation and dedication made the successful completion of this project possible. The goals were realized through the key roles played by each individual and the resultant collaborative efforts, innovative contributions, and unwavering commitment. Each of the projects was created through embracing sustainability and fostering a sense of community and shared accomplishment. Invaluable contributions from each have been acknowledged, leaving a lasting impact on the success and significance of this endeavor.

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Where Architecture and Furniture Design Overlap in The Terms of Circularity: A Cross-Disciplinary Field

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ABSTRACT: The paper explores how circular economy (CE), and its practices relates furniture design and architecture in the case of the Regenerative Cabin (fig.2), The Regenerative Cabin Table (fig. 4) and The Lyngby Table (fig. 6). The paper examines the interdisciplinary field of design and architecture and how thinking and concepts of CE establish relationships across disciplines. The study is a qualitative empirical case-study based on observations, qualitative interviews with the architects involved and analysis of documents, files, and digital presentations from the design processes. The theoretical perspective is theory on circular economy (Preston, 2012, Ellen-MacArthur Foundation 2015) and Actor-network Theory (ANT) (Latour 2005, Yaneva 2009). The understanding that materials and ideas such as circular economy are actors with agency is crucial to the research and ANT-inspired mappings of dynamic actors. The cabin acts as an intersection point of architecture and different avenues of furniture design. Preston´s definition of CE helps us find the overlap that happens between architecture and furniture design, when architectural waste of certain dimensions fails to find relevance within the architectural field, that same waste can find purpose in furniture design. Findings from the study indicate that circular economy and a circular mindset might suggest new possibilities that require close collaboration between actors from a cross-disciplinary field. The case also indicates that practices like this need a well-designed network to achieve the desired results.

KEYWORDS: Circular Economy, Architecture and Furniture Design, Upcycling Practice, Design Trajectory

INTRODUCTION

Buildings globally have a substantial impact on the environment, accounting for nearly 40 percent of total energy consumption (including 60 percent of electricity usage), approximately 12 percent of global water consumption, 40 percent of waste generated by volume, and 40 percent of material resource consumption (World Resource Institute 2016). These numbers highlight the significance of the environmental impact the building industry has and hence its transition to a circular economy is fundamental (University of Cambridge 2016). In the 1970s, Swiss architect and economist Walter Stahel introduced the concept of processing materials in a 'closed loop,' where what is typically considered 'waste' is regarded as a valuable resource (Stahel & Giarini 1989). Stahel termed this approach a 'Cradle-to-Cradle' system, distinguishing it from the Linear model known as Cradle-to-Grave (Stahel & Giarini 1989). He emphasized the importance of prolonging product life through repair and remanufacture, concepts that are now recognized as essential components of the Circular Economy (Stahel and Reday-Mulvey 1981).

The focal point of this study is a small building and two pieces of furniture design based on circular economy principles. Therefore, they are well-suited cases to study the design processes that such an ambition entails. They also provide an opportunity to examine how architecture and furniture design can be interwoven in practice. Studies conducted to analyse examples of application of CE principles in select architectural projects from China and France suggest that there is a need for enhancing technological systems such as BIM integrating them into cloud systems to enable information sharing across various sectors (Dongez, Manisa and Basdogan 2021). This recommendation stems from the understanding that the building life cycle extends beyond the architecture and construction sector. It operates as a cyclical system and economy, involving collaboration with diverse sectors such as supply and waste management (Dongez, Manisa and Basdogan 2021). When it comes to furniture and other industrial products, up to 80% of their environmental impacts are determined at the design phase, the linear pattern of “take-make-use-dispose” does not provide producers with sufficient incentives to make their products more circular (European Commission 2020). Thus, transitioning to CE will be a systematic change, one which will need to work with the relationship between design considerations at the beginning of a product's life and their implications for the product's takeback stage for closing resource loops in a circular economy (Franco 2019). Product-Service Systems (PSSs) theoretically have a great potential to enhance sustainability and produce closed-loop resource flows, but their net impact depends crucially on several factors that need to be carefully assessed in all cases (Rizos, Tuokko and Behrens 2017). When it comes to adoption of CE in practice, in the Danish furniture industry for instance, a report from the Lifestyle and Design cluster provides an insight into how CE is a concept and approach which is new for most companies to begin with and that a handful of them have started to work with CE (Copenhagen Design Agency, Lifestyle & Design Cluster 2018). In a Danish context, the struggles over waste as a resource have intensified (Moalem, et al. 2023) and with ambitious goals set by the government to implement CE in the built environment and better waste management (Denmark 2021), it seems that cross industry collaboration might be one of the solutions to achieve goals of becoming circular. This ties in to the research question of this paper:

How do circular practices bring furniture design and architecture together in the case of the Regenerative Cabin, The Regenerative Cabin Table and the Lyngby Table?

1.0 METHODS

This case study is data-driven selected (Neergaard 2007) due to its close connection between furniture design and architecture. The studied case is atypical from an architectural point of view, as its conditions of origin are very distinctive as an architectural development work with highly reduced constraints and functional requirements. The furniture projects are also atypical as they are parts of a master thesis project. The case can best be defined as a so-called critical incident (ibid.) which can be understood as a part of a developmental process. A semi-structured and qualitative interview (Kvale and Brinkmann 2009) was conducted with architect Declan Ericksen (architect D), who was responsible for the furniture project, and two semi-structured and qualitative interviews were conducted with architect Morten Emil Engel (architect M), who was behind the architectural project. Document analyses (Lynggaard 2010) were performed on materials from both projects, such as PowerPoint presentations, sketch materials, applications, and descriptions. Both architects provided archival material from their processes, which is included in the empirical investigation. Additionally, both authors of the article have followed the process of both the furniture, which was a graduation project, and the house, which was built on the institution's campus and thus publicly accessible. One author has continuously documented the creation of the house through photographs. All interviews were transcribed and analysed through condensation of meanings, as well as both empirically driven and theory-driven categories. All selected quotes have been lightly edited for written language and subsequently approved by the informants. Through the coding and analysis process, it has proven relevant to incorporate new analytical concepts and continually include additional empirical evidence from notes and visual materials in the qualitative research process, which, with (Maaløe 2002), can be described as exploratory integration.

2.0 THEORETICAL FRAMEWORK

2.1. Actor-network theory

Actor-network Theory (ANT) is a theoretical framework from which this paper draws on the thinking and research of (Fallan 2008, Latour 2005, Blok and Jensen 2009, Callon 1984, Latour and Yaneva 2008, Yaneva 2009) ANT is, in essence, an alternative, materially oriented sociology with a relational perspective. ANT is known for assigning significant importance to detailed empirical descriptions and accounts. At the core of ANT is the concept of an actor, which encompasses both human and non-human actors. An actor is characterized by making a difference in a given context. In an ANT perspective, action emerges as a network effect. In ANT understanding, architecture and furniture design can be seen as a kind of stabilized actor-network that has emerged in a construction process involving many and diverse actors. The collective and relational aspects in design and architecture, as well as design processes, are thus emphasized in this perspective. Actors cannot only be extremely heterogeneous, but they are typically also mediators (Latour 2005) meaning they are not neutral. They make a difference by colouring, influencing, or modifying the other actors they meet. Another central concept is the obligatory passage point (Callon 1984) which everyone with a given interest must deal with. It could be, for example, a building permit or a specific functional test of a piece of furniture before it can be introduced to the market. Another relevant concept is obligatory passage point, (Callon 1984) which defines something that everyone with a converging interest must address. Albena Yaneva (Yaneva 2009) has conducted extensive observational studies on Office for Metropolitan Architecture and has noted how materials, rules, requirements from clients, constraints, previous projects, old models, remnants of foam, and much more appear to be in a constant fluid movement in the drawing room. Based on this, she suggests that design is re-design because typically fragments and elements, both physical and conceptual, from various projects are incorporated and assembled in architectural proposals. By observing how materials and projects change scale, form, and relation to other actors, she emphasizes the dynamic and changeable nature, referring to all these movements and dynamic actors as design trajectories. It is implied here that they neither have a clear starting point nor an endpoint. “In the trajectory, there is no finality, but a state of incompleteness” (Yaneva 2009, 62). As argued by Latour and Yaneva (Latour and Yaneva 2008), architecture—and one could extend this to furniture design—is not static. They change, but very slowly (ibid.).

2.2. Circular economy

New consideration of CE in the field of architecture have highlighted the opportunities that lie in new approaches related to adaptive reuse of architectural and building elements (Charytonowicz & Skowronski 2015). Over the years the definition of CE has had multiple iterations and applications, however the underlying principle of all the definitions is the better use of our resources (Rizos, Tuokko and Behrens 2017). Achieving a fully closed circulation of components in the building industry is challenging, nevertheless despite these challenges, the proposed concept could be implemented incrementally by exploring the reuse of materials derived from demolished buildings (Charytonowicz & Skowronski 2015).

Another principle of CE, adaptive reuse, in architecture can mean the process of reusing an obsolete, damaged or faulty building by changing its function and maximizing the reuse and retention of existing materials and structures. Adaptive reuse as a terminology is often used interchangeably with refurbishment, retrofitting, conversion, material reuse etc., with overlapping definitions (Shahi, et al. 2020). One of the key CE principles that practices such as furniture design rely on is optimizing resource yields, design for remanufacturing, refurbishing, and recycling to keep components and materials circulating in closed loops. (FURN 360 2018).

Advancements in product design and material choices have effectively lowered the expenses associated with transitioning products into increasingly tighter closed loops. This has been achieved without compromising the structural integrity or functionality of the products. While material selection is undoubtedly pivotal in facilitating circularity, other crucial elements for achieving economically viable circular design include the incorporation of modular and standardized components, as well as a focus on designing for disassembly (Ellen Macarthur Foundation 2013). Design for Disassembly (DfD) is one of the key skills in CE, with the aim of optimising designs and materials for production and repeated use in closed loops (Ellen Macarthur Foundation 2013). Some of the fundamental principles of DfD encompass several key aspects:1) Thorough documentation of materials and methods to facilitate the deconstruction process, 2) Designing connections and joining methods that simplify dismantling, meaning minimizing chemical and welding connections and favouring bolted or screwed connections, 3) Strategize to separate non-recyclable, non-reusable, and non-disposal items, 4) Develop designs with simple structures and forms, facilitating the standardization of components and dimensions, 5) Ensuring that the design reflects considerations for labour practices, productivity, and safety, acknowledging the impact on the deconstruction process (Rios, K. Chong & Grau 2015). These principles collectively contribute to the overarching goal of Design for Deconstruction, emphasizing an approach that anticipates and facilitates the eventual disassembly of structures or components with an emphasis on efficiency, recyclability, and safety (The Pennsylvania State University 2008).

3.0 ANALYSIS

3.1. Analysis strategy

Based on the empirical data and initial analyses, as seen in figure 1, an actor-network theory-inspired mapping of the various actors who, in various ways, contributed to the realization and construction of The Regenerative Cabin has been developed. Subsequently, The Regenerative Cabin Table and the Lyngby Table were mapped with a focus on material flow and sources of inspiration, using the same methodology. Through this mapping, four examples of CE connections between the architectural project and the furniture design were identified. These are shown below and are marked with their respective colours. Furthermore, they were selected for further data production and analysis using Actor-Network Theory and concepts from CE.

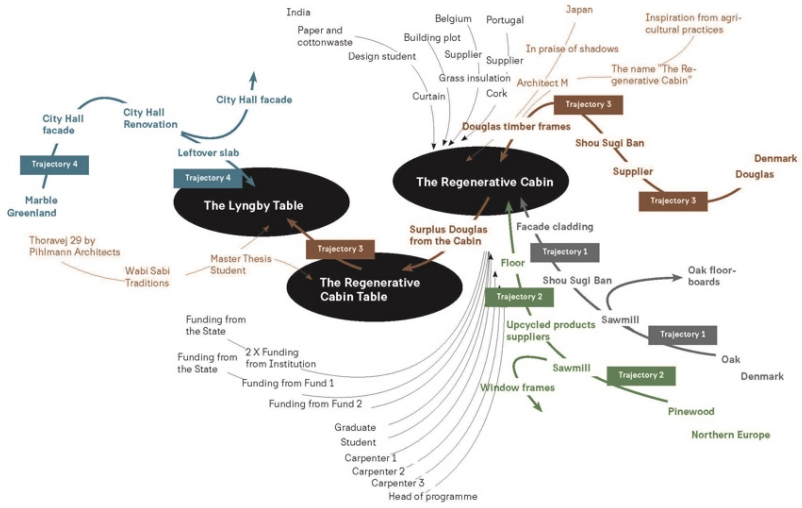


Figure 1: Mapping that shows four design trajectories of circular economy in the case studied. Source: (Authors 2024)

4.0 THE CABIN AND THE TWO TABLES

4.1. The regenerative cabin

The Regenerative Cabin was built as a development project by architect M, served as an experimental venture to investigate the architectural characteristics and ambience of biogenic building materials. Biogenic can, according to Professor Anne Beim be "(…) defined as renewable, regenerative, naturally grown materials, materials originating from plant growth, etc." (Beim 2023, 22). The Cabin also acted as a response to the many temporary pavilion projects that were being planned and constructed in connection with UIA and Architecture Capital 2023. When asked about his motivation behind the project, architect M says:

> It was a real struggle to actually do a real sustainability project, because they are sort of governed by different dynamics, you know, clients that want things done in a different way or for competitions you have to deliver in another way. It always somehow ended up being difficult to really get this sustainable mindset really integrated. (Architect M, interview 1).

The inspiration for the overall characteristic and visual performance of the Cabin came from the Japanese philosophy of Wabi-Sabi, where the beauty of imperfections in surfaces and materials are celebrated.

The name emerged as architect M was inspired by the regenerative movement in agriculture, where the philosophy is to improve the soil through farming practices and avoid extractive land use, which is the prevailing practice today. Thus, the name "The Regenerative Cabin" was coined. The name was intended to serve as both inspiration and provocation.



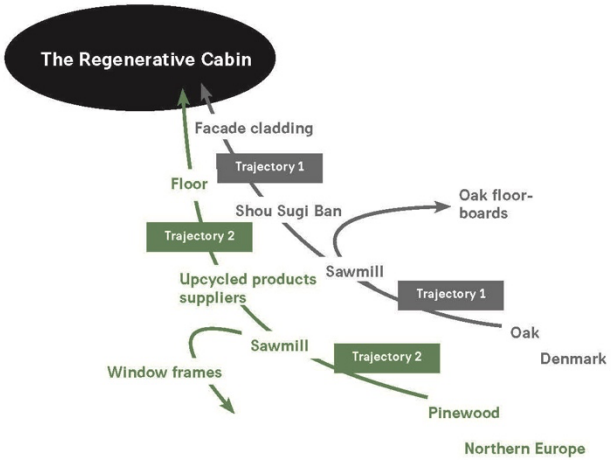


Figure 2 (left): The Regenerative Cabin. Source: (photo by Søren Rønholt 2023)
Figure 3 (right): Diagram showing the oakwood trajectory and the pinewood trajectory. Source: (Authors 2024)

The cabin was constructed with longevity in mind, but, since the project was meant for UIA 2023, it would have a rather short life span and was to serve as a showcase structure. Therefore, the structure was designed for disassembly using traditional timber framing made from locally grown and milled Douglas wood. The joints were constructed without the commonly used steel brackets and nails that weaken the structure over time and lead to rot due to continuous condensation. Dense wood-fibre boards capable of carrying the facade cladding were chosen as the windbreaker and were fastened with special high-performance beechwood nails as an alternative to typical steel nails. On top of this, Douglas wood joists and cladding shingles were added. The shingles utilized in the facade design were derived from off-cuts of oak floorboards produced locally. The floor was crafted from end-grain pinewood blocks, an upcycled product derived from off-cuts of window frame manufacturing. For the final interior cladding, the walls were adorned with expanded cork. This material, harvested every 9 years from Portuguese cork oak trees, not only provides insulation but also contributes to acoustic damping and regulates air moisture. The ceilings were adorned with eelgrass panels. Minimal steel elements were incorporated, including the steel roof designed for quick mounting and dismounting for future transportation needs, and a durable steel stair structure.

There are two types of wood that were upcycled in the project: trajectory 1 (pinewood), and trajectory 2 (oakwood). They are actors that change status, function, and role in the case. They are design trajectories (Yaneva, 2009) each with their own paths and dynamics as showed in fig. 3.

Design trajectory 1 is essential to the design of the façade. Architect M got in touch with a sawmill that had off-cuts from the production of oak floorboards. When a floorboard is cut to the length it is intended to be sold in, there is a leftover piece with a random length. This is an offcut. The sawmill donated a number off-cuts to the project, and here Architect M saw the opportunity to design the house's shingle facade. These off-cuts, initially discarded due to cosmetic imperfections and faults, played a substantial role in shaping the design of the facade. Their relatively short length and the intentional overlapping arrangement, aimed at diverting water from the facade, contributed to the distinctive staggered appearance that has since become an iconic element of the design. The shingles underwent a surface-burning process called Shou Sugi Ban, as a natural means of protection. This method involved burning away the wood's sugars, diminishing its appeal to fungi. Architect M explains it in this way:

> (…) they have a lot of offcuts that they're not using. So, they wanted to donate that. They had varying width and length. What I could get from them sort of informed the actual design of this shingle façade. You must reverse your design process, and you must adapt your design to what you can get. (Architect M, interview 1).

In a manner like the pinewood example, oakwood as an actor moves through various actor-networks: From 'living-oak-trees' to the industrial production of 'oakwood-floorboards', thereby defines as 'oakwood-offcuts-boards´. Finally, it is enrolled (Callon 1984) by Architect M in the actor-network of the house project, where it is stabilized as a shingle facade. Unlike the house floor, which was supplied as upcycled flooring from the supplier, it was Architect M who was responsible for the upcycling of the facade. The donated 'oakwood-offcuts-boards' became a obligatory passage point (Callon 1984). If the facade was to materialize, Architect M had to deal with the available and very specific dimensions, quantity, and characteristics of the 'oakwood-offcuts-boards' by hand. Norms and preferences for the length and width of floorboards become, in this example, an invisible co-designer (Møller 2018), a non-human actor that influences the appearance of the facade.

The nature of the first processing stage (at the sawmill), through which the mentioned off-cuts arise, is crucial but not determine for how the second processing stage (the façade design), unfolds. When considering the production of floorboards from an ANT perspective, it can be observed how two separate actor-networks are constantly constructed: the oakwood-floorboard and the oakwood-offcut. This is a simultaneous and inseparable dual production.

Design trajectory 1 is the house's end grain floor, which is constructed from upcycled pinewood. The trajectory of the pinewood illustrates how it initially is a living tree that becomes part of industrial production with the purpose of making window frames. This involves a specific actor-network that transforms the actor 'pinewood' into ´pinewood-window-frames'. In this process, a translation occurs, where parts of the initial pinewood actor-network are

separated from the ´pinewood-window-frames´ and now have the status of being 'surplus-pinewood'. From here, another translation takes place; an actor-network, including the sawmill and suppliers of upcycled materials, enrols (Callon 1984) the 'surplus-pinewood´, which now change status to 'upcycled-end-grain-pinewood-floors' in the new actor-network, that constitutes the Cabin. This is how the design trajectory of the pinewood gets enrolled and translated and becomes the floor of the house.

4.2. The regenerative cabin table

The table (fig. 4) is crafted from surplus Douglas fir that was used in the making of The Regenerative Cabin along with reclaimed steel plates that were obtained from a local blacksmith. Rather than refinishing the steel, the project embraced its imperfections and natural patina. The assembly of the table's trestles is facilitated by stainless steel furniture bolts that enable structural integrity and the convenience of disassembly. The table embodies the principles of adaptive reuse of the surplus material from an architectural project and design for disassembly, to facilitate easy stowage and maintenance. The wood was given the same charring treatment as the other elements for the cabin, as per the Shou Sugi Ban technique.



Figure 4: The Regenerative Cabin Table. Source: (photo by Søren Rønholt 2023)

The Douglas timber, which is produced in Denmark, was purchased by Architect M for the construction. It has been manufactured and treated using the Shou Sugi Ban technique, which gives the structure a burnt and protective surface. During the construction period, Architect D was a graduating student and had Architect M as a supervisor. Architect D had been studying for an extended period how materials that were left over in an architectural context could be repurposed in a furniture context. Architect D set out to design a table for the house. In this case, surplus Douglas timber from the construction project became the primary material for a table called The Regenerative Cabin Table. Architect D describes the design process:

> It was cool working with Architect M (ed.) because it was a small enough project that I could kind of keep track of where is the material surplus and kind of looking at are we generating off cuts or other things that could be of use? And then using that as a kind of the material palette. (Architect D, interview 1).

As the cabin is partially constructed from surplus materials, it also generates its own surplus materials. Considered as an actor-network, a large number of heterogeneous materials stabilize (Callon, 1984) as the house itself. At the same time, other materials become decoupled, now forming smaller and less extensive actor-networks. In the process, some of the surplus materials were taken over by other students or left. This can be viewed as a localisation of the loop surrounding the materials going into the cabin. All the actors that became a part of the network around the cabin and its furniture help fulfil idea of closing the material loop (Ellen Macarthur Foundation 2013) for the project.

For Architect D, the surplus materials from the house construction also become an obligatory passage point (Callon 1984) because Architect D uses the remnants as the starting point in the form of a “material palette”. It becomes material-driven design and an example of how design can be understood as re-design (Yaneva 2009).

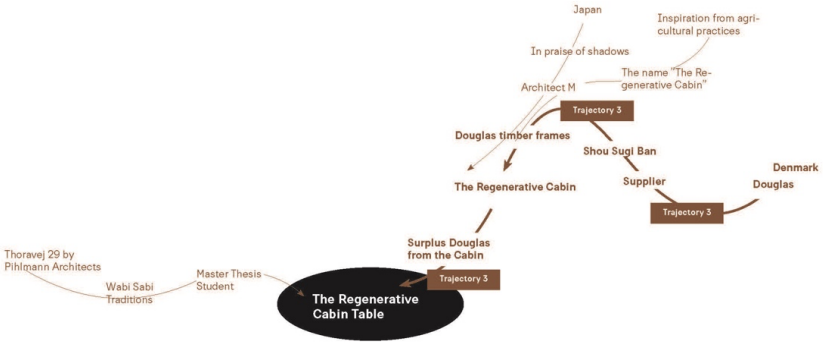


Figure 5: Diagram showing design trajectory 3: from Douglas trees to timber frames and to a table. Source: (Authors 2024)

The design of the table does not arise from an idea or a sketch. Architect D designs the table based on the programmatic requirements from the house, an average adult human body and as a re-design of the material pieces left after the architectural design and construction process. This can be defined as a ‘rethinking device’ and as per CE advocates, it has proved to be a powerful new methodology, capable of sparking creative solutions and boosting

innovation rates for industries (Ellen Macarthur Foundation 2013). Since the inception of the Regenerative Cabin was showcase working and building with biomaterials, and as per CE principles, the idea of using more bio-based materials is that they can return to the biosphere as feedstock (Rizos, Tuokko & Behrens 2017). Although all the biomaterials used in the cabin don't go back to the Earth's crust, they do feed into the furniture made for the cabin, thus redefining a system and paving the way to possibly re-design the system (Ellen Macarthur Foundation 2013), of architecture and furniture design and bring them closer together in a symbiotic relation.

4.3. The Lyngby Table

The Lyngby Table demonstrates a design approach rooted in materials and adaptive reuse. Through collaboration with an architectural office and a municipality, an imperfect slab of Greenlandic Marble sourced from the facade became a focal point for architect D, the designer of the table. This particular marble was intentionally procured from Greenland in the 1930s, despite more affordable alternatives in Europe, to support and stimulate the Greenlandic economy. The table (fig. 3) serves as an invitation to perceive imperfections and blemishes as distinctive opportunities for intricate detailing. A structural test hole in the marble, rendered it unsuitable for reuse in the building renovation and was hence transformed from a defect into a design catalyst and a distinctive detail in the table. The table is a manifestation of adaptive reuse and material driven design.



Figure 6: The Lyngby Table. Source: (photo by Søren Rønholt 2023)

The Lyngby Table demonstrates how leftover materials from two different architectural projects migrate, converge, and acquire new meaning. The trajectory (trajectory 3) of the Douglas fir goes from being a living tree, processed into wooden elements, which become the structural framework of the cabin (figure 7). As the cabin is constructed, there is also a surplus of materials, which architect D chooses to use. A marble slab, originating from Greenland and having served as a facade panel on a city hall for many years, is separated from its temporary actor-network, the city hall, and enlisted by architect D. This is design trajectory 4. Through architect D's practice, the two trajectories converge: one stemming from Greenland consisting of marble, and one from Denmark consisting of Douglas fir. Architect D brings them together in the same actor-network and stabilizes them as a table. The two trajectories are united (figure 7).

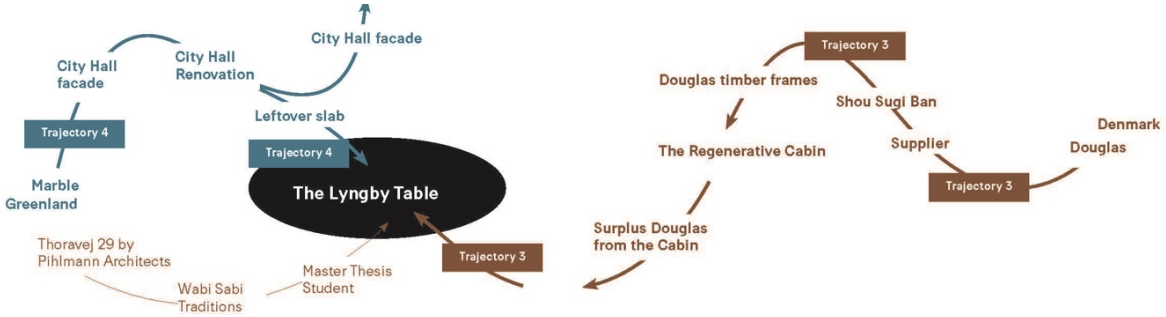


Figure 7: Diagram showing design trajectory 3 and 4 in the case of the Lyngby Table. Source: (Authors 2024)

The example illustrates a design process that integrates and brings together highly diverse actors in a formation that becomes the table. When asked about how Architect D understands the design process in relation to the way he has previously worked with furniture design, he responds:

> It flips it (the design process) so that it's material driven, and then there's probably a step of iteration where you make a model or sketch based on the existing material that you have, and then have to kind of figure it out with the workshop. (Architect D).

It is pointed out here that the design process is material-driven, and the possibilities of working with the materials in a workshop also come into play. It is easier to continue working with off-cuts than with used wood, which may

contain nails and the like. The sketch work is based on the available materials, becoming a mandatory passage, and the manufacturing possibilities in a workshop become an invisible co-designer.

5.0 DISCUSSION

As stated earlier on in the paper, that CE empathises on closing loops (Ellen Macarthur Foundation 2013), the fact that the Regenerative Cabin is a small, bespoke architectural project, whatever material was utilised by architect M in its construction would have had some surplus or off-cuts. That is precisely what happened, but without another architectural project to utilise its residual/surplus material. This is where the opportunity for that material to find relevance in a smaller scale, furniture. This connection was possible thanks to the fact that architect M was supervising architect D for his master thesis project. In terms of ANT, these two human actors already had a common network, their roles as student and supervisor.

Here we observe design processes that are based on materials and require a deep knowledge of materials and an understanding of how they can be processed without damaging machinery in the workshop. With reference to Yaneva (2009), it is clear that when we follow materials as design trajectories, a second understanding of both the house and the furniture emerges. They become temporarily stabilized networks with a physical form and a recognizable function. However, this is only until they are separated, moved, or repaired, as they are designed to be. The house and the furniture are just a phase in their trajectories. The design processes are not examples of an initial strong idea or sketch that evolves into a finished project.

The design work here consists of identifying possibilities. Architect M sees architectural possibilities in materials that emerge from the actor-networks generating floors. Architect D identifies possibilities in materials separated from new construction and renovation. Both produce houses and remnants, which become a potential in the field of furniture design. Another notable observation is that both are deeply engaged in aesthetic traditions from Japan, forming a common actor-network of inspiration from specific techniques (Shou Sugi Ban), a preference for dark shades, and a celebration of what others might consider flaws in the materials. This actor-network, in which they both participate, becomes a strong co-designer in all three cases. As Ingold (2009) points out, design is not a matter of an idea in the mind of the designer that needs to take an external form: “Against this hylomorphic model of creation, I argue that forms of things arise within fields and flows of material.” (Ingold 2009).

CONCLUSION

At the beginning of the investigation, we raised the following questions: How do circular practices bring furniture design and architecture together in the case of the Regenerative Cabin, The Regenerative Cabin Table and the Lyngby Table? Based on the investigation, the following specific conclusions can be drawn:

The house and the two pieces of furniture are built based on principles from Design for Disassembly, aiming for repairability and easy to disassemble. This has influenced the choice of construction and the design of joineries.

The construction of the cabin is, in terms of materials, essentially based on a combination of biogenic materials, new materials and upcycled materials. Upcycling has either occurred at a supplier or as part of the on-site design process.

In this case, both a house and surplus material are produced. This suggests that the construction process leads not only to a house but also to a certain number of surplus materials.

The furniture exemplifies upcycling from one or two architectural projects, namely a new construction and a renovation. It is easier to upcycle new materials, such as off-cuts, than used materials, such as a facade stone. Architect M and Architect D share an interest in the Japanese wabi-sabi tradition, including a distinct aesthetic expression and the idea of celebrating imperfection. This seems to be a productive inspirational framework that aligns well with circular economy principles.

Architecture and furniture design are brought together in the case in such a way that the starting point for the furniture is surplus materials from two architectural projects (the cabin & the city hall). Both architects, in their design work, have started from the aesthetic, constructive, and tectonic potentials of residual materials, thus practicing material-driven design. Architect M and Architect D both mention that there has been a need for new knowledge about materials and how they could be used and crafted in the design process. They have both been deeply involved in the actual construction processes, thus transcending the role of advisory architects and moving into a more craft-oriented role.

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Finite Earth, Open-Ended Architecture? Framing a Qualitative, Ecological Perspective on Housing

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ABSTRACT: In contemporary housing development, the dichotomy between quantitative and qualitative approaches underscores a fundamental tension. This article explores the significance of this dichotomy and its complex implications on the ecological relationship between humans, the built, and the natural environment. The paper asks: *how can the contemporary architectural practices of housing development encompass a qualitative ecological perspective?* This will be elaborated by examining the shortcomings of 'numerical environmentalism' to reevaluate the role of technology in mediating human-environment relationships, questioning not only the quantitative methodologies we utilize to assess environmental impacts, but also critically examining how we currently design, build, and maintain our built environments from within this rationalist mindset. To initiate the conceptualization of a qualitative alternative, a practice guided by an ethic of care is proposed to form a critical lens through which the contemporary practices of housing development can be challenged. As contemporary practices often prioritize numerical assessments and scalable solutions over context-specific, qualitative considerations, the research will advocate for what can be considered a qualitative 'open-ended' architectural paradigm, embracing uncertainty, time, the capacity to induce and absorb change, diversity, material proximity, and so forth. This is elaborated in a logical framework of concepts, principles, and incompatibilities, and further visualized as a spectrum covering the dichotomy foregrounded. At its core, the key message of this research is a call for architects to rethink their approach to housing development to embrace care relations and open-ended architectural principles with ambitions to cultivate a more harmonious relationship between humans and their surrounding environments.

KEYWORDS: sustainability, care, time, ecology, housing

INTRODUCTION

The primary goal of the discourse on 'absolute sustainability' is to evaluate the environmental impact of our actions, practices, products, and built environments against Earth's finite ecological capacities. Today, this is achieved by quantifying these impacts and capacities into numerical data for comparable measures (Hauschild, Kara, and Røpke 2020; Ohms et al. 2019; Andersen et al. 2020; Brejnrod et al. 2017). Fostered by advances in quantifying the nine planetary boundaries, the absolute sustainable discourse marks a turn in environmental assessments from relative assumptions towards unambiguous and absolute conclusions that introduce a mindset of unconditional certainty throughout many decision-making processes in the built environment. This turn has proven a strong communicative potential – not only by raising public awareness but by inciting political action through, for example, clear-cut reduction targets. Yet, this paper argues that there are significant pitfalls in solely relying on quantitative methodologies for transitioning society in a greener direction, foremost rooted in the reductive characteristics of the discourse, abstracting the world's intricacies into uncompromising data for the benefit of 'spreadsheet-compatibility'. Pitfalls that necessitate precaution for undesired side effects and misconceptions that may potentially fuel further the ecological instability between the built and the natural environment. Adding to this the dominating rationalist worldview spread wide by global capitalism, the paper claims that the real challenge of contemporary 'sustainable' architecture may well be to maintain a qualitative closeness to our environments.

Motivated by this, this paper seeks to challenge the practices that quantitatively give form to, change, and maintain our built environments. More specifically, the target of the paper will be the built environment of housing development, which, from 2015 to 2020, accounted for approximately 66% of new construction in Denmark (Tozan et al. 2023). In this context, the aim is to challenge the conception of designing, building, and maintaining housing through the lens of an ecological approach capable of considering the nuances that current reductive strategies may not. The ambition is not to provide any definite or categorical answers but to frame a spectrum of concepts, principles, and incompatibilities that may provide insights into '*how contemporary architectural practices of housing development may encompass a qualitative ecological perspective*'. For this reason, this paper will be directed mainly against what can be considered quantitative housing development, where future inhabitants are unknown to developers and architects, and not the specific case where a private client consults an architect as the communicative framework surrounding the ladder usually by default represents a qualitative exchange of ideas, ideals, thoughts, visions, and ambitions. Nevertheless, it is the hope that any conclusions may inform all kinds of architectural practices with principles that do not enforce distance, but in-depth closeness and consideration for the intricate ecological frameworks we all operate within.

1.0 METHODOLOGY

The methodology of this paper follows critical argumentation, utilizing existing theories and concepts to build a logical framework encompassing this foregrounded perspective of a qualitative practice. This framework will be

outlined as a spectrum of concepts and principles, extending the span from normative contemporary practices of housing development to what will be conceptualized as an 'open-ended architecture'. This will be achieved by first critically unfolding the issues relating to quantitative assessment models, to outline possible pathways for theoretical and ethical approaches that may foster a qualitative alternative. These will be considered 'first principles', and thus constitute the lens through which the research question will be addressed. Throughout the article, various examples will be made from cases relating to the topic of the paper. This includes the 'Reduction Roadmap' (Reduction Roadmap 2024), which will used to demonstrate the potentials and conflicts surrounding the numerical and rational form of environmental assessment, as well as extracts from the projects in the '4>1 Planet, Next Generation Architecture' initiative, that led up to the UIA World Congress of Architects in Copenhagen 2023 (4 til 1 Planet 2023), which is intended to demonstrate and validate possible qualitative architectural responses to the logical framework developed.

2.0 NUMERICAL ENVIRONMENTALISM: POTENTIALS, SHORTFALLS, ALTERNATIVES

As stated above, it is indisputable that quantitative methodologies play a central role in the green transition. A recent and quite successful example demonstrating *how* is the 'Reduction Roadmap', dedicated to keeping the carbon footprint of our built environment within an equivalent corresponding to the Paris Agreement's threshold 1,5°C temperature increase (Hill-Hansen et al. 2022). By presenting categorical targets within different time perspectives in easily comprehensible graph visualizations, the 'Reduction Roadmap' exemplifies a communicative potential, being openly supported by more than 500 central actors within the Danish construction industry at the time of writing (Reduction Roadmap 2024). And, by using these declarations of support to induce pressure for more ambitious climate legislation, the 'Reduction Roadmap' equally demonstrates the capacity to influence political decision-making processes. However, examining the foregrounded conclusions, it becomes apparent that the 'Reduction Roadmap' is not as much a 'roadmap' *prescribing* possible pathways towards an environmentally stable practice, as it is a 'postcard' numerically *describing* the destination we aspire to reach. As such, quantitative targets might show us where to go, but not necessarily how to get there. Reduction is inevitable, but how we choose to reduce is a multifaceted question with no categorical answer.

To draw the contours of an alternative qualitative approach, it is first necessary to comprehend more fundamentally the shortfalls of the normative quantitative models and how they may affect practice. On account of Thomas S. J. Smith's book 'Sustainability, Wellbeing and the Posthuman Turn' (Smith 2018), devoted to examining the exact issues of what Smith coins 'numerical environmentalism', the following sections will first outline three central arguments against present numerical conventions before engaging the task of framing an alternative.

2.1 Abstraction and commodification

The foremost argument built against the conventions of 'numerical environmentalism' is that quantified reductions conceal significant and overarching issues behind the rationality of categorical 'facts' (Smith 2018). In this light, methods, such as the calculation of carbon footprints and the quantification of planetary boundaries, simplify climate change to issues of carbon emissions, reducing the transgression of thresholds to a technical matter of innovation. To build this argument, departure is taken from Heidegger's conception of technology as a means for society to uncover and interact with the world (Heidegger 1977). As such, humanity's means of quantifying the world is co-constitutive to how we, as humans, position ourselves within the world. By reducing the Earth's ecosystems into mere numbers, we partake in environmental commodification, making the ecological landscapes compatible with the neoliberal conventions that guide our society towards ambitions of endless expansion. We create a version of 'nature' without entanglements – a scalable 'nature' (Tsing 2012). On a global political scale, these issues are demonstrated in concepts like 'carbon offsets' (Carbon Offset Guide 2024); the trading of 'carbon credits' (Carbon Credits 2022); or the establishment of 'markets for ecosystem services' (Ecosystem Marketplace 2023). According to Thomas S. J. Smith, these technological 'solutions' thus devalue nature into what Heidegger phrases as a 'bestand', understood as a 'standing reserve' or 'stockpile' for the disposal of humanity alone (Smith 2018).

2.2 Objective and universal

The common understanding that numerical environmentalist approaches are apolitical, uncontroversial, and universally applicable can equally be drawn into question, as universality would require overlooking various conflicts, interests, and perspectives surrounding the definition of such approaches, including the diverse local conditions and contexts in which they are implemented (Smith 2018). Concepts like planetary boundaries may thus appear neutral until efforts to operationalize such concepts planetarily uncover biases, cultural differences, political and economic incentives, etc. What may be considered sustainable or beneficial in one region or culture may not be in another.

2.3 Dichotomizing culture and nature

By drawing a comparison to the 19th-century English philosopher John Stuart Mill's 'harm principle', Smith argues that the planetary boundaries passively overlook unsustainable actions until the point at which these actions transgress thresholds (Smith 2018). Consequently, this subtly enforces the anthropocentric division of 'culture' and 'nature' by building on the notion of a cultural environment whose actions impact an isolated and fragile concept of the natural environment. As a result, coping mechanisms are promoted over more radical solutions to the dysfunctional dynamic between humans and their surrounding ecological systems.

2.4 Caring as alternative

Considering these arguments in the conception of an alternative practice, Smith proposes revisiting the 'deep ecological movement' of Norwegian Philosopher Arne Næss and his notion of the ecological 'Self', understood as

a relational reconceptualization and enlargement of the ego with the world (Naess 1995; Smith 2018). Consequently, such reconceptualization transforms environmental preservation from what may be considered actions of altruism to actions of 'Self'-preservation, maintaining that our existence is contingent on recognizing the interconnection between us, as humans, and everything non-human. According to Smith, such a perspective on being in the world aligns with a feminist 'ethic of care', directed toward fostering connections, emotional responses, and caring dispositions (Smith 2018). As a moral theory, it traces back to the research of psychologist Carol Gilligan who uncovered that in moral dilemmas, women, unlike men, tended to focus more on the particular circumstances and responsibilities involved, rather than relying on generic and categorical principles or rules (Gilligan 1982). In this light, caring can be seen as a reciprocal, context-bound, relationship-oriented process between actors, aimed towards maintaining and meeting the needs of what constitutes one's world, encompassing oneself, each other, and the environment, both living and non-living (Collins 2015). Thus, by altering the understanding of actors from being seekers of self-interested goals to being engaged in relationships of care, our conception of 'well-being' is equally altered, from being concerned with ambitions of quantified growth and consumerism to being directed towards processes of maintenance and continuation. This outlines a societal organization echoing the principles of post-consumerist thinking, where new and broader environmental agencies become possible. Thus, if our numerical assessments give us a target and direction, the reciprocal practice of care between us and our environments may be the vehicle to get us there. The challenge, however, now lies in figuring out how our contemporary housing practices may comply.

3.0 CONFRONTING ARCHITECTURE'S PRACTICES OF TODAY

Building on this understanding, this section will draw into question the contemporary practices of housing development. This will be elaborated through a series of 'incompatibilities', that, when unfolded, may introduce challenges and possibilities to inform principles of a qualitative practice. Without a doubt, more misalignments can be uncovered, but for now, the focus will be on 'scalability, ideals, and uncertainty', then 'time, durability, and change', and finally 'technology, alienation, and the material world'. Along each section, different extractions from the '4>1 Planet, Next Generation Architecture' projects, will aim to demonstrate some of the considerations foregrounded. This is not an effort to frame specific solutions, but a demonstration of what positions architecture can take towards these incompatibilities when 'care' guides the practice.

3.1 Scalability, ideals, and uncertainty

To outline the first incompatibility, we should consider again the 'Reduction Roadmap', and how the graph visualization's categorical appearance leaves little room for ambiguous and novel thinking. In the article 'Visualizing Uncertainty and Vulnerability', Peg Rawes, professor of Architecture and Philosophy at The Bartlett School of Architecture, points to how similar visualizations of the recent pandemic's progression in the UK portray the picture of the government's apparent successful course of action during the lockdown, but in reality, are built upon incomprehensible and unstable data (Rawes 2020). According to Rawes, the visualizations are utilized to conceal uncertainty and promote ideological motives behind what appears to be scientific validity and authority (Rawes 2020). As such, the visualizations demonstrate the employment of a biopolitical power pushing an 'objective truth' infused with political incentives. Revisiting in this light the argument that 'numerical environmentalism' is neither apolitical nor universally applicable encourages us to reconsider what unspoken influences quantitative methodologies such as the 'Reduction Roadmap' impose on our practices. What is insinuated here is that methods of assessing, calculating, visualizing, and mapping might be oriented to generate specific behaviors and responses in line with various underlying ideological or speculative motives, with or without intention. It is a mechanism not unlike Foucault's concept of 'disciplinary power':

> […] discipline fixes; it arrests or regulates movements; it clears up confusion; it dissipates compact groupings of individuals wandering about the country in unpredictable ways; it establishes calculated distributions (Foucault 1995, 219).

Following this line of thinking, by uncritically continuing these normative methodologies of assessing, we exercise this disciplinary power in a self-perpetuating process that fabricates fixed solutions, keeping our practices in place by opposing innovations that transcend the frameworks of quantitative models. Consequently, as the 'Reduction Roadmap' advocates a staggering 96% reduction of carbon emission in the production of new housing (Hill-Hansen et al. 2022), it subtly delimits our understanding of possible solutions to those quantifiable while discouraging efforts to develop qualitative approaches as these may not be scalable nor appear economically viable in a numerical manner. This may not completely prevent qualitative practices, but it does elevate engagement in context-specific qualities and challenges into an out-of-the-ordinary practice for the architect engaging with scalable housing development.

Thus, it appears an architectural practice encompassing ambitions of quantitative scalability may be incompatible with any practice guided by a context-bound 'ethic of care'. To further situate this incompatibility within the practices of housing, one can look to the writings of John Habraken, former head of The Department of Architecture at MIT and initiator of 'the participation movement' that today is strongly linked to 'the open building practice'. As Habraken argues in his book 'Supports: An Alternative to Mass Housing', there is a paradox in implementing 'ideals' as generic solutions because: "what is ideal […] is subject to the imperfection of man's existence" (Habraken and Valkenburg 2011, 10). As such, 'ideals' as well as 'care' share the properties of being context-bound. What Habraken was criticizing was the functionalist belief in a universal one-size-fits-all design of the 'ideal' dwelling – not unlike a strictly quantitative approach to sustainable architecture. In mass housing, the individual was dissolved into the masses at the cost of personal identity and significance just like a scalable numerical environmental engagement will oppose strategies and considerations capable of recognizing unique contextual conditions. Although Habraken's ideas derive as a resistance to the mass housing projects of the '60s, contemporary housing development today shares the same power dynamic between architect and dweller, necessitating the dweller to take form and fit into the

overarching architectural ambitions and not the other way around.

For the practice of housing development to be ‘scalable’ it must thus exclude ‘diversity’ following numerical environmentalist ideals, meanwhile repeating the misconceptions that gave ground to the mass housing projects we reject today. To use the term of anthropologist Anna Tsing, ideals and care relations are ‘nonscalable’, built up by ‘elements of social landscapes’ (Tsing 2012). Fitting these qualities into a scalable practice would require a diversified approach, not unlike Habraken’s division between ‘support’ and ‘infill’ describing respectively a building's permanent constructive system, as a product of the architect, and the building's dynamic functionality, independent of the constructive dimension and assigned to the individual to operate (Habraken and Valkenburg 2011). In short, the ambition must be to allow diversity and uncertainty to exist between the invariable vectors of a scalable framework.



Picture 1: The 'Planetary Pavilion' by architectural office 'Lokal' exemplifies the integration of nonscalable elements within a scalable framework. Through participatory programming facilitated by a modular wood beam structure, the dwelling adapts to evolving user needs, fostering flexibility and inclusivity. Source: (Sandra Gonon 2023)

3.2 Time, durability, and change

By questioning the ambition of ‘ideals’, new opportunities emerge in architecture's relation to ‘time’. As Jeremy Till argues in ‘Architecture Depends’: “time is the medium that most clearly upsets any notion of static idealized perfection in architecture” (Till 2013, 65). In the seminal ‘How Buildings Learn’, Stewart Brand unfolds a similar argument, proclaiming foremost that “architects should mature from being artists of space to becoming artists of time” (Brand 1994). By putting ‘time’ before ‘space’, Brand does away with the conventional strive for architectural perfectionism, implying that ‘ideal form’ is an ambition correlating with only a snapshot of contextual circumstances that will not be the same tomorrow: “All buildings are predictions, all predictions are wrong” (Brand 1994, 178). Refraining from predetermining formalistic ideals may thus allow time to emerge as a dimension of significance equivalent to the predominant three dimensions wherein architecture's spatiality unfolds – it matures architecture from ‘form’ to ‘process’.

In their book ‘Buildings Must Die: A Perverse View on Architecture’, Jane M. Jacobs, professor at Yale, and Stephen Cairns, professor, and leader of the research group Future Cities Lab at ETH, argue how architecture’s ‘obduracy’ might be the foremost precursor to architectural obsolescence (Cairns and Jacobs 2014). By using the verb ‘obdurate’, commonly used to describe a personality trait, Cairns and Jacobs emphasize the slow pace, almost static state, of most contemporary architecture, without denying it as something ‘alive’ or ‘dynamic’ – without denying it a relation to time. What is important here is to not mistake obduracy for durability. According to them, architecture should never be regarded as durable, as continuous processes of maintenance and investment are necessary to sustain architecture's value (Cairns and Jacobs 2014). In this light, one can see the value of architecture as being subject to processes of social constructs more than static structural and material aspects. Thus, when architecture is cared for its value is maintained, meanwhile, obdurate architecture that appears durable might eventually lose value and become obsolete as a consequence of societal mechanisms, such as the neglect of care and maintenance. Contrarily, a more fragile architecture requiring ongoing care will potentially maintain its value over time. Cairns and Jacobs further state that “A building that changes over time is also an architecture that can stand in time” (Cairns and Jacobs 2014, 126). One can even argue that ‘time’ in architecture appears in the form of ‘change’.

What is being foregrounded here is a concept of ‘change’ as a form of adaptation different from the modernist understanding of ‘flexibility’ where the empowerment to and nature of ‘change’ is something preconditioned by the

architect's ingenuity and prior intention, and therefore biased by limited imagination. It is not about submitting to a predetermined scheme but about being capable of adjusting to unforeseen conditions, and by doing so, adjusting the condition itself. A fitting concept to elaborate on this dynamic is French philosopher Catherine Malabou's notion of 'plasticity' as an 'intelligent flexibility':

> To be flexible is to receive a form or impression, to be able to fold oneself, to take the fold, not to give it. To be docile, to not explode. Indeed, what flexibility lacks is the resource of giving form, the power to create, to invent or even to erase an impression, the power to style. Flexibility is plasticity minus its genius. (Malabou 2022, 12)

As a concept derived from neuroscience, 'plasticity' describes the brain's ability to change its structure and function in response to experience and development (Malabou 2022). But within architecture, 'plasticity' is relevant as it lets us consider 'adaptation' as an 'exchange of changes' between actors and environments. In this understanding, 'change' is a reciprocal process just like 'care' and presents the capacity to challenge fixated norms and presumptions, such as the invariable metrics of a scalable practice. If managed and given the right intention, this form of 'change' can become an expression of 'care', not only in the form of thorough transformations, but also more cautious alterations, maintenance, and continuation. Or even as the 'exchange' of identity and significance between an architectural environment and its user. This is also 'change', but with a different velocity and trajectory. It is more than just materialistic change; it is relational change. Or, as Bruno Latour and Albena Yaneva argue in their article 'Give Me a Gun and I Will Make All Buildings Move':

> […] a building project resembles much more a complex ecology than it does a static object in Euclidian space. (Latour and Yaneva 2013, 109)

Again, 'time' is being centered as the necessary fourth dimension needed to introduce this ecological relation between the built and the natural environment. Time is a necessity for change, while change is a medium for care. Accordingly, if 'care' is about 'maintaining' through this concept of 'change', the idea of maintenance-free architectures or components thus excludes 'time' by rejecting 'change' in favor of an illusion of 'durability' that can only lead to obsolescence. Through change, we reinvigorate relevance, and when we maintain the built environment, we care about the natural environment.



Picture 2 and 3: The fragile yet solid rammed earth walls of the project 'Naturlig Rækkerne' by architectural office 'Reværk' demonstrate the relation between time, change, durability, and care. The construction is in a constant process of change, and without care, the walls would return to earth over time. But by reapplying clay and pressure, the structure can be maintained easily thus renewing its relevance. And by caring for it, the earthen walls provide shelter, accumulate warmth, and regulate moisture. It is an exchange of care. Source: (Sandra Gonon 2023)

3.3 Technology, alienation, and the material world

Recalling again Heidegger's inquiry into the 'essence of technology'; technology is for humans a means of 'enframing' or 'revealing' the material world we inhabit (Heidegger 1977). When relating to our environment, we do it through a sensory system deeply entwined with technology. As we understand 'care' as a relational exchange between actors and environments, questioning our understanding and use of technology appears fundamental in the ambition to alter our position from an anthropocentric utilitarian perspective toward one guided by care.

In the article 'Architecture, Technology, and the Body: From the Prehuman to the Posthuman Society' Jonathan Hale, architect and professor at The University of Nottingham, argues how increasingly complex technologies distance humanity from the natural environment which derives an 'alienation' that also manifests itself in the relationship between the architect and the architecture (Hale 2012). Hale builds his arguments upon the concepts of 'transparent' and 'opaque' technology, formulated by Peter McCleary, former professor at Penn University (McCleary 1988). Drawing reference to both Heidegger's notion of 'ready-to-hand' and Merleau-Ponty's 'blind man', McCleary elaborates that 'transparent technology' allows its user to experience the environment through the 'technic', that is a tool, machine, or equipment, similar to how the blind man experiences the environment through his cane, causing the cane itself to become 'transparent' and withdraw from his consciousness. Contrary, an 'opaque technology' allows its user only to experience the 'technic' experiencing the environment, thus withdrawing instead the environment from the user (McCleary 1988). As 'transparent technology' allows the user's attention to be directed toward the material at hand, it uncovers, for the user, embodied knowledge of the material world. Contrarily, as technology becomes increasingly autonomous and sophisticated, human perception is directed towards 'opaque' controls and interfaces, distancing the user from the environment, eventually leading to a digitalized abstraction of reality where 'black-box' technology reduces material knowledge into mere data (Hale 2012, 519).




Picture 4 and 5: The thatched facade of the pavilion 'Thatched Bricks' by the offices 'Leth & Gori' and 'Rønnow' in collaboration with 'CINARK'. Thatching is a craft that today is done by a skilled craftsman utilizing a variety of 'transparent technologies', such as the thatcher's 'leggett'; a flat board attached to a handle used to drive the reeds into place. In this instance, the façade was constructed off-side as façade-elements, and subsequently transported for on-site montage. This allowed for a somewhat 'scalable' production, enabling a broader variety of reed quality to be used, as well as providing logistical potentials in terms of improved workflow and sheltering. In combination with the sophisticated insulating bricks, it demonstrates the possibility of working within the spectrum of 'transparent' and 'opaque' technologies. Source: (Sandra Gonon 2023)

In architectural practice, this technological advancement has made available digital tools capable of overlooking aspects of material constraints for scalability. But as the use of these complex tools preconditions a homogenized perspective on the material world, it follows that concealed flaws, potentials, characteristics, and differences easily are neglected. On the other hand, approaching the material world in its full essence requires a practice of immersed attention, qualitative, precise, and investigative, and thus 'nonscalable'. At one end of this spectrum stands the architect, or the 'draftsman' of the 'Albertian Paradigm' as architectural historian Mario Carpo has phrased it (Carpo 2013), that through his pen (or cursor) orchestrates architectural interventions, unrestricted by context or material specifics, thus scalable and replicable. At the other end stands the 'craftsman', who through his transparent technologies is directly engaged in the material world, uncovering its complexities and unique possibilities. Hale further elaborates:

> The carving out of a special niche for design within the construction process […] involves a necessary degree of alienation between thinking and building, which is at the same time both liberating and troubling. (Hale 2012, 524)

To the practice of the 'modern' architect, an inherent aspect of alienation is thus a constituting quality. But, this alienation is a spectrum, framed by a tension between 'drafting' and 'crafting'; 'opaqueness' and 'transparency', or as architectural theorist Marco Frascari coins it; 'constructing' and 'construing' – the 'knowledge of construction' and 'the construction of knowledge' – derived from the etymology of technology's 'techne' and 'logos' (Frascari 1983). In the article 'Tell the Tale Detail', Frascari points to building detail as the technological dimension for balancing this tension, as opposed to the plan which historically has been given predominance in the 'modern' architectural practice (Frascari 1983). Frascari writes:

> In the details are the possibilities of innovation and invention, and it is through these that architects can give harmony to the most uncommon and difficult or disorderly environment generated by a culture. (Frascari 1983, 2)

What Frascari frames is the tectonic dimension of architecture, as an expression or manifestation of intention transcending scales, bound together by construction techniques, materiality, structure, craftsmanship, and cultural context. Through this dimension, an architecture that either enforces distance or uncovers ecological interrelations between the built and the natural environment is formed. As alienation is default to the architectural practice – and scalable housing development in particular – aspiring towards transparency and material proximity over programmatic functionality and space planning appears to be the objective for a practice of care. This, however, does not mean fostering a blind focus on materiality alone, as the British anthropologist Tim Ingold argues:

> […] the prevailing emphasis on materiality obstructs our understanding of the fields of force and circulations of materials that actually give rise to things and that are constitutive of the web of life. (Ingold 2012, 429)

Thus, a closeness to the material environment encompasses recognizing the underlying ecological network of forces and complex systems that influence the production, distribution, use, and disposal of materials. For the architect of care, fully grasping this complex ecological network is a major challenge, but one that can be reduced when materials are locally available, unprocessed, non-composite, and biodegradable.

CONCLUSION

Conclusively, this section aims to unify the concepts, principles, and incompatibilities elaborated throughout the article, to fully frame the spectrum drawn between the dichotomy of quantitative and qualitative practices. At one end of this spectrum the practice of 'close-ended architecture' unfolds and towards this extreme is where most contemporary practices of housing development are situated. At the other end the conceptualization of a 'open-ended architecture' takes place, favoring the qualities derived from 'the practice of care'.

Thus, a completely 'open-ended architecture' does not follow a conventional life span encompassing a production phase, use phase, and end-of-life phase. It represents much more an assemblage of various life cycles, interchangeable, perceptible to change, and thus capable of engaging in relations of care and maintenance. A completely 'open-ended architecture' should therefore not be conceived as an isolated form, typology, or even as a singular building, restricted to Euclidean space, but as a rhizome that unfolds in all four dimensions of space and

time, with no beginning, end, center, or fringe. What is ‘open-ended’ is a continuous process of adjustments more than a solid form of certain intention. Through the lens of an ‘open-ended practice’, we do not conceive our natural environments as a ‘standing reserve’ but may, contrarily, understand our built environments in this way. Not with the aim of endless expansion, but with the aim of ongoing continuation. If ‘close-ended practices’ promise ‘solutions’ to the ecological crisis in the form of categorical targets, an ’open-ended practice’ acknowledges that there are no quick fixes or solutions and that what is needed is a fundamental change in attitude towards our position and role in this crisis. Thus, an ‘open-ended practice’ represents a continuous endeavor to change for the better.

Table 1: Unravelling the spectrum between the poles of ‘close-ended’ and ‘open-ended’ reveals a wide range of concepts, principles, and incompatibilities. Source: (Petersen, 2023)

Close-ended architecture	Open-ended architecture
Guided by rational reasoning	Guided by an ethic of care
Quantitative (measurement)	Qualitative (meaning)
Generic	Specific
Scalable	Nonscalable
Universal	Context-bound
Certain	Uncertain
Predetermined	Indetermined
Form	Process
Obdurate	Malleable
Static	Dynamic
Submitting	Adjusting
Flexibility	Plasticity
Maintenance-free	Maintenance-capable
Homogeneity	Heterogeneity
Opaque	Transparent
Alienation	Proximity
Constructing	Construing
Drafting	Crafting

No practices can be conceived as completely ‘open-ended’ or ‘close-ended’. In reality, every practice is situated somewhere in between the outer poles. Thus, being solely ‘open-ended’ or ‘close-ended’ may be more a theoretical conception than a practical one. However, as elaborated above, the architectural practice of housing development tends to default towards being ‘close-ended’, driven by our rationalist mindsets, political constitutions, societal norms, professional conventions, assessment methods, etc. Thus, aspiring towards the qualities of an ‘open-ended architecture’ may be the broadest applicable conclusion to be taken from this paper.

Finally, one might wonder what position the architect should take within this spectrum of extremes. In addressing this, it is relevant to distinguish the everyday urban fabric as our housing from the singular manifestations of architecture that constitute our cultural, political, and educational institutions. In the book ‘Palladio’s Children’, John Habraken makes a similar distinction and further claims that today's everyday urban environment, or ‘field’, is being addressed through an architectural heritage that stems from the creation of monumental objects (the Albertian paradigm) and that this mixing of fundamentally different practices results in conflicts and dissatisfactions echoing the problems outlined above (Habraken and Teicher 2005). Habraken further states:

> We [architects] share another heritage as well, the heritage of master builders acting within living, growing, ubiquitous and autonomous built environment (Habraken and Teicher 2005, IX)

Thus, maybe the ‘architect of care’ should start by revisiting the pre-modern practices of vernacular housing, where our built environments were conceived as living ‘fields’, and where contextual sensitivity, material closeness, and the craft of the hand were constitutive qualities, emphasized over the scalable, extraordinary, and ideal.

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Pop-up Earthquake Architecture for Integrating Practical Experience and Social Responsibility into Architectural Education

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ABSTRACT: The last major earthquakes that struck extended urban and rural areas in Southeast Türkiye left thousands of buildings demolished or uninhabitable. After the urgent demand for temporary housing is resolved, there will be a need to provide quick solutions for adequate social spaces for the affected communities. Additionally, considering the large number of collapsed or heavily damaged buildings in past earthquakes in Türkiye, schools of architecture should prepare architects capable of understanding and applying the basic principles of seismic design for buildings. Moreover, given the social responsibilities that the profession entails, future architects should also be able to engage with the communities they serve, thus providing spaces that are not only safe but also suitable for their needs. This paper describes an architectural studio with a twofold aim: firstly, making a meaningful contribution to a small community living in the earthquake zone by identifying their post-disaster needs for spaces of social interaction; and secondly, providing undergraduate students with applied knowledge and skills in conceiving, designing, planning, producing, assembling, disassembling, transporting, and installing a pop-up structure. The design-build studio was organized through a reductive selection of design proposals, where ultimately one project was selected for actual construction and another for further construction detailing. The proposed approach of using a hands-on and embedded teaching format to explore pop-up architectural design responses, following design-for-disassembly principles, ensured students' in-depth learning of construction techniques and the associated important roles of detailing and drawings for materializing a project. Due to time and material limitations, however, not all students benefited from the possibility of building their own designs, leading to a sometimes-estranged studio environment.

KEYWORDS: Post-disaster recovery, design-build studio, timber construction, active learning, hands-on teaching

INTRODUCTION

The two major earthquakes that struck extended urban and rural areas in Southeast Türkiye on February 6, 2023, caused more than 50,000 casualties and left over 200,000 buildings either collapsed or severely damaged (Mertol et al. 2023). During the months that followed that disaster, the main recovery efforts focused on providing emergency housing (e.g., (Florian 2023)), with the most common solution coming in the form of 'container cities.' Although containers and other unit-based solutions provided a quick, easy-to-transport, and easy-to-install solution, the result was extended residential areas without spaces for social engagement for the people. Moreover, in villages and small towns around the major cities, communities were left to their own devices to find quick alternatives to housing, leading to much less attention paid to providing any sort of social space solutions.

The short-term need for providing quick solutions for adequate social spaces for the affected communities entangles itself with a long-term one: rising earthquake awareness among the professionals involved in building construction. The majority of the building stock that has been destroyed or severely damaged during earthquakes in Türkiye lacks code compliance and adequate structural detailing, displaying poor construction quality and architectural design faults (Cogurcu 2015). This evidence highlights the failure of all building-related professions to provide citizens with safe spaces to live and demands a rethinking of the way we are forming those professionals. Schools of architecture should prepare architects capable of understanding and applying the basic principles of seismic design for buildings. Moreover, given the social responsibilities that the profession entails, future architects should also be able to engage with the communities they serve, thus providing spaces that are not only safe but also suitable for their needs.

This paper describes an architectural design-build studio with a twofold aim: firstly, making a meaningful contribution to a small community living in the earthquake zone by identifying their post-disaster needs for spaces of social interactions; and secondly, providing undergraduate students with applied knowledge and skills in conceiving, designing, planning, producing, assembling, disassembling, transporting, and installing a pop-up structure. The main challenge, therefore, is how to set up a studio where students can produce an architectural project according to their level of design, knowledge, and skills within 15 weeks, and, more importantly, ensuring that this project fits the needs of a community affected by a major disaster.

1.0 METHOD

1.1 Teaching strategy

The challenge posed by the aforementioned aim led to three main studio targets:

- Balancing project size versus complexity: The social gathering project should be small enough for the studio to cover the entire design-to-production process in 15 weeks. Simultaneously, it should be complex enough to fulfil the learning requirements of a 3rd Year Architecture Studio, as defined by the school's curriculum.
- Revising the students' role in the process: Unlike traditional forms of architectural studios, the intention of building one proposal (due to logistic and economic constraints) necessitates rethinking the self-assumed designer's role of each team in all steps of the design-to-production process.
- Including the transportation variable: Given the lack of public facilities and proper infrastructure in the disaster areas and the impossibility of students staying away from the campus for extended periods, the project must be constructed far from the selected site and then transported there.

To address these targets, the methodology applied to the studio is based on the following teaching strategies:

- Focus on pop-up architecture: This approach commonly refers to small and strategic interventions in public spaces to improve social interaction (Lähdesmäki 2016). Unlike top-down approaches promoted by urban regeneration initiatives, pop-up structures rely on bottom-up approaches. Successful enhancement of public space lies in strategically placed small interventions. By identifying the main aspects of the local context, these comparatively smaller, flexible, and adaptable projects can provide more viable and feasible solutions to respond to and mitigate the problems faced by a community after experiencing a major earthquake.
- Select a place with a small community: This ensures that key social needs can be clearly identified. A village with 5,000 inhabitants, located 10 km from one of the major affected cities, was chosen. Through surveys and conversations with villagers, at least two possible locations were selected for the temporary installation of the project.
- Introduce design-for-disassembly (Crowther 2005): Rooted in the notion of circular design, this approach involves conceiving architectural projects not only to be assembled but also to be disassembled. It evaluates design proposals in terms of material availability, transportation issues, and on-site installation logistics.
- Establish a hands-on approach to design through scale models: Since the feasibility of proposals hinges on their potential for assembly/disassembly and transportation, the process of building a scale model, with its associated problem-solving demands and practical experience, served as both an experimental and testing platform for the designs.
- Apply differentiated teaching techniques: Based on differentiated grouping and stepped tasking (Algozzine and Anderson 2007), special attention was paid to students' individual skills and interests. This allowed for the reorganization of teams according to the differentiated tasks required throughout the entire studio process.

1.2. Studio settings

The studio was originally planned to cover three major stages, as summarized in Table 1. It involved 42 students, 4 instructors, and 2 assistants (PhD architecture students). Among the instructors, three possessed practical knowledge in timber construction, and one of them also had expertise as a structural engineer.

Table 1: Overall description of the initial design-build studio planning. Source: (Mauricio Morales-Beltran)

stage	*goals*	*method*
conceptual proposals	exploring conceptual ideas for pop-up interventions in the village	Introducing pop-up architecture through case studies; group of students + instructors visit & study the village; surveying for defining social needs; presentation & discussion with the whole studio; class is organized in 14 teams; each proposes a design in either site (A/B), considering design-for-disassembly aspects; external review panel assess the potential of each proposal for further development
project development	defining one project to be built in the next stage	Introducing differentiated & hands-on teaching approaches: class is reorganized in two units, each comprising former 7 teams; within each, 2 teams develop the chosen design; 2 teams develop logistics, transportation and disassembly strategies; 2 teams produce 1:50 and 1:10 scale-down models, and one team adjusts its work to unit's demands; each unit presents its revised proposals; studio instructors choose one proposal to be built
detailing & construction	building-up a prototype and advanced development of construction details	Understanding & assessing construction detailing through development of a 1:1 prototype (team A) and detailed 1:5 models and assembly/disassembly strategies (team B); revising design & construction decisions based on hands-on learning experiences; producing construction and project drawings

The first stage involved the development of conceptual design proposals for further selection and development. This conceptual phase aimed to (1) gather key site information through a technical trip, (2) acquire pop-up architecture-related knowledge through a case study exercise, and (3) obtain conceptual proposals by organizing the 42 students into teams of 3. In this stage, students were informed about material constraints, specifically the use of commercially available timber sections, and constructive constraints such as the necessity of having a structure that could be prefabricated, assembled, disassembled, and transported. Although commonly used in timber construction, the use of steel plates and connectors was prohibited to encourage critical thinking about timber connections and reduce the need for expert carpentry labour. Moreover, this initial stage aimed to stimulate students' competitive natures and encourage the development of projects that best suited the community's needs.

The second stage involves the development of only two selected proposals, one for each chosen site, so the class is divided into two units. Each unit is supervised by one instructor, while the other two instructors support teams with topic-specific tasks. In this stage, within each unit, teams separately focus on design development, production of scale-down models, and study of the assembly/disassembly process and design issues related to the transportation of the final project. This differentiated tasking was introduced to encourage further development of the projects while benefiting from having at least two teams working on the same topics for each project, thus enabling the selection of the best idea to implement. The third stage basically encompasses the construction of the prototype and the development of all building construction drawings.
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2.0 RESULTS

The results of the applied methodology, studio settings, schedule, availability of materials, and instructors', assistants' & students' commitment and performance can be summarized in the scheme displayed in Figure 1.

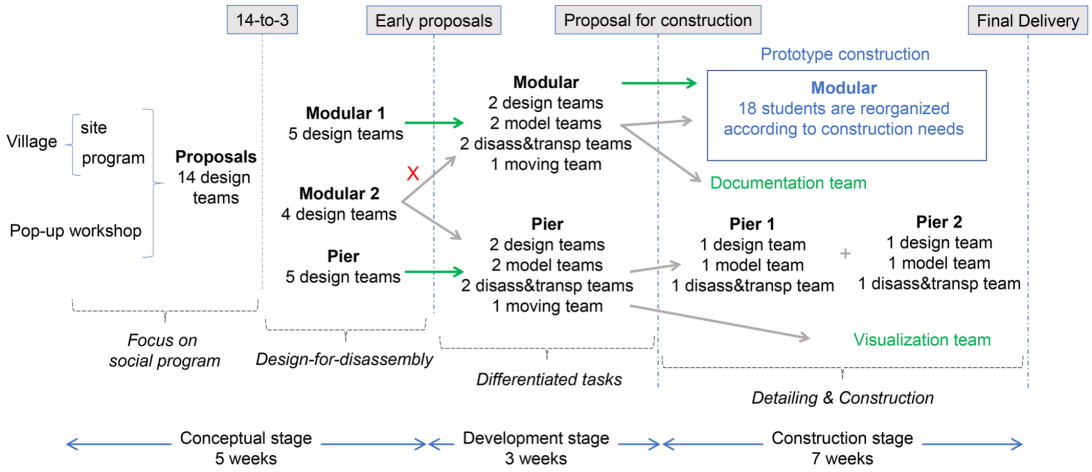


Figure 1: Schematic overview of the applied studio methodology, including the main conceptual, development, and construction stages. The imaginary timeline runs from left to right. Source: (Mauricio Morales-Beltran)

2.1. Site trip by a few students and instructors

Lack of funding and the uncertainties associated with traveling to a post-disaster area, prevent students' participation in the site trip. Only seven students and two instructors visited the selected village to gather information on the site and the needs of local people, six months after the earthquake. They collected technical, cultural, and topographical information and conducted an architectural site analysis, which concluded with the selection of two project sites, and a third one to be used if authorization to use either of the first two was not obtained (Figure 2). Following discussions with villagers, the decision was made to design a social space where the community could gather for events such as weddings, anniversaries, the exchange of local products, open cinemas, and religious activities, as well as providing a safe and playable area for children. All collected information was shared using an internet storage platform, ensuring accessibility to all documents, and encouraging discussion among all students.



Figure 2: Aerial view of the village displaying chosen sites A – River side and B – Cemevi. Site C - School was surveyed in case the other two could not be used, so it remained as the last option. Basis image source: Google Earth. Source: (Ömer Can Bakan)

2.2. The 14-to-3 reduction

The sought design simplicity and the students' natural inexperience in dealing with projects that should be continuously reassembled led to a homogeneous response in terms of conceptual proposals. On the one hand, modularity emerged as the most logical design response to the challenge posed by transportation and assembly/disassembly issues. On the other hand, most proposals reflected design conceptions based on the notion of a building rather than on open and semi-open spaces, which were pointed out by the instructors as suitable during the studio discussions. Since there were a few exceptions, instructors decided to reorganize the 14 design teams around three promising conceptual proposals. Two of them, based on the idea of modularity, were placed on the river side, while the third one, a sort of pier-like intervention, was placed on the Cemevi site (Figure 3).

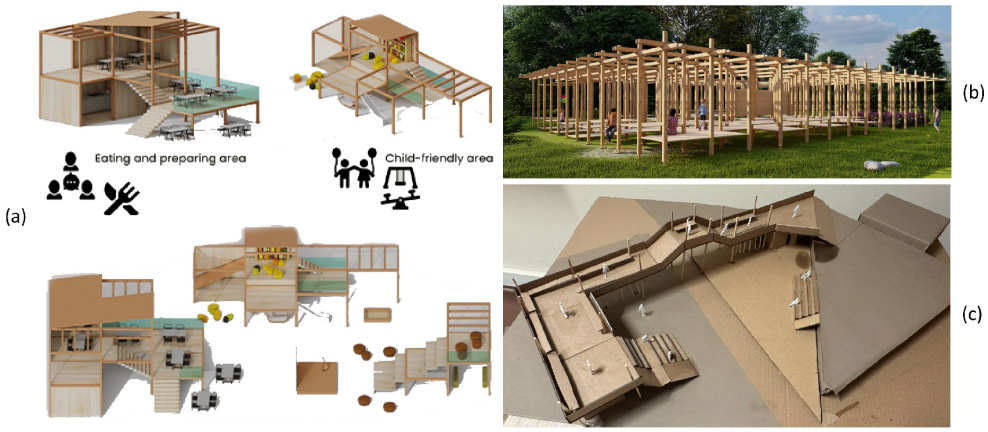


Figure 3: Selected early proposals: (a) – (b) Modular 1 and 2, on the river side, and (c) Pier on the Cemevi site. Source: (Design Studio Students 2023)

2.3. Early proposals

Each of the three selected proposals offered different potentials and setbacks. Modular 1 focused on the social needs of the community, yet it lacked unity as a proposal. Modular 2 offered a clear definition in terms of construction, yet it produced repeated narrow spaces contradicting the idea of openness and multifunctionality of the targeted project. The Pier displayed a powerful intervention integrating the open areas in front of the Cemevi, yet it posed many questions on its transportability and reassembling process. To widen the design options and explore solutions, 4-5 teams revised each of these proposals under the leadership of a single instructor. This decision aimed at avoiding confusion among the students, enabling fast progress on the design definitions.

In this stage, students were provided with a preliminary list of available materials to guide the design developments towards materialization. They were also required to submit designs using common architectural drawings (site plan 1:500, floor plans and sections 1:100, system sections 1:20, details 1:5, revised material list) to better articulate their ideas and practical solutions, preferably using timber. Timber was chosen as a primary building material due to time limitations, local availability, minimal equipment requirements, and the low learning curve of the construction skill set. Simultaneously, to reduce the knowledge gap, students were provided with practical timber construction solutions. A site trip to an actual timber structure of similar dimensions and features to the one planned was organized to further increase their understanding of the material and construction system.

After two weeks of intense work, all 14 teams presented their revised versions of the originally selected proposals. The instructors selected Modular and Pier (Figure 4). The former, based on the idea of modules, allowed easy adaptation to the ever-changing needs of the social gathering space, offering versatility to produce closed and semi-open spaces using a simple assembly logic. Although revised proposals of Modular 2 were not selected, the chosen proposal benefited from Modular 2's constructive approach based on a single-level grid scheme, simplifying the construction process by removing the original different levels. The Pier, on the other hand, offered a gathering exterior area that could be used as an extension of the religious facility existing in its vicinity. Moreover, conceived as an urban space with several functional layers, it could potentially host different social activities and create a real meeting area in the centre of the village.

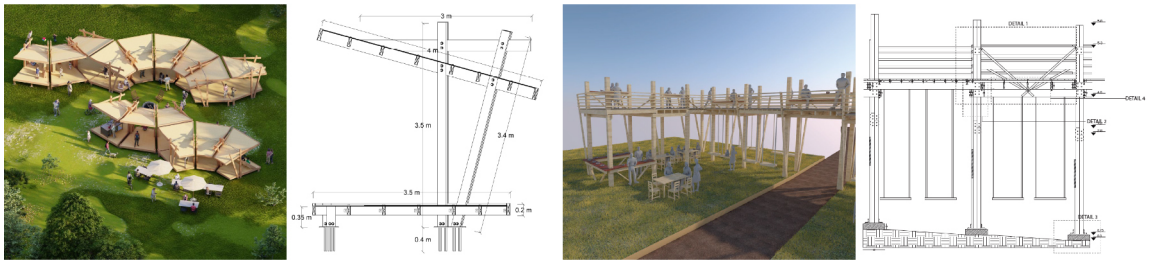


Figure 4: Render visualization and system section of the Modular (left) and the Pier (right) projects. Source: (Design Studio Students 2023)

2.4. Proposal for construction

All former design teams were reorganized in this stage according to specific tasks (Figure 5). This strategy, based on assigning differentiated roles to teams, aimed at providing students with specific learning skills (e.g., model making, problem-solving) while benefiting from faster progress in the development of the projects. In addition, design teams were supported by structural engineering consultancy provided by one of the studio instructors. The goal was to ensure that the building construction systems were in line with a structural logic, thus avoiding late additions of extra structural reinforcement. As a consequence, the three projects are based on modules structured by truss-like vertical elements, acting as columns. Although the cantilevering roof of the Modular project was somewhat challenging, the major challenge was posed by the Pier's variations which acted as true bridges and hence required further studies to ensure compliance with both gravity- and seismic-based design principles.



Figure 5: Differentiated roles in the project developments of the Modular: design team (left), physical modelling teams (middle), and assembly/disassembly, transportation and logistics teams (right). Source: (Ecenur Kızılörenli)

After a few weeks of developing the projects, the Modular was selected for prototype construction, while the Pier was set as a backup plan for further development. This decision, made by the instructors, was based on the following criteria:

- Although the Pier project was also based on modules at that moment, their variation and mostly their sizes posed many challenging questions, yet to be solved in a short time. On the contrary, the inherent constructive simplicity of the basic module of the Modular project showed a clear path for prototyping it.
- Due to the relatively small size of the Modular's prototype to be built, having 42 students working on it seemed quite impractical.
- The need for a backup project arose for two reasons: not having permission yet to build on the river site (thus requiring an alternative project and site) and the uncertainty of securing additional funding/support for two projects.

After the selection of the Modular for construction, the design teams behind the Pier could not agree on future directions for its further development. Due to an until-then-undetected tension among the students and the added lack of motivation after their project was not selected, instructors allowed the split of the whole Pier team into two sub-groups. Each of them worked on a specific design and construction system of the proposal. Consequently, by the 9th week of the semester, there were again three projects (Figure 6).



Figure 6: Development of the projects by the 9th week: Modular (left) and the two variations of the Pier (right). Source: (Design Studio Students 2023)

2.5 Final deliveries

During the final 'detailing & construction' stage of the studio, further differentiated tasks were assigned. One of the Modular teams was assigned to data collection and archiving. Over the last semester weeks, the data collection team was responsible for gathering materials, precedents, pictures, and files from the other teams. Additionally, they were required to monitor and document the 1:1 prototyping process and promote the studio work on social media. Another team, originally part of the Piers' project, was asked to enhance the visual communication quality of the final deliveries, due to their visual representation abilities. This visualization team's assignment was presentation-enhancing of images, consistent visualization of the projects, and elaboration of the construction booklets for each project.

This strategy allowed the rest of the teams to focus on either proper construction drawings or the construction of the prototype. The Pier teams worked simultaneously on construction drawings and models of their proposal at different scales. Due to the difference in size and complexity of the Modular and Pier projects, the pace of the development expected for each project was different. For instance, final 1:5 models of each project were not developed simultaneously (Figure 7).



Figure 7: Non-simultaneous development of Pier 2's and Modular's 1:5 models of the modules: during the same week (left) and final deliveries (right). Source: (Mauricio Morales-Beltran)

Moreover, targets were different for each process: while the Modular team used the models to foresee possible construction and assembly issues and to explore practical solutions, the Pier teams used the models as testing for construction insights and consistency. Therefore, while the construction drawings of the Modular were developed in an almost linear timeline, the construction drawings of the Piers' projects were better informed through an iterative process of feedback (Figure 8).

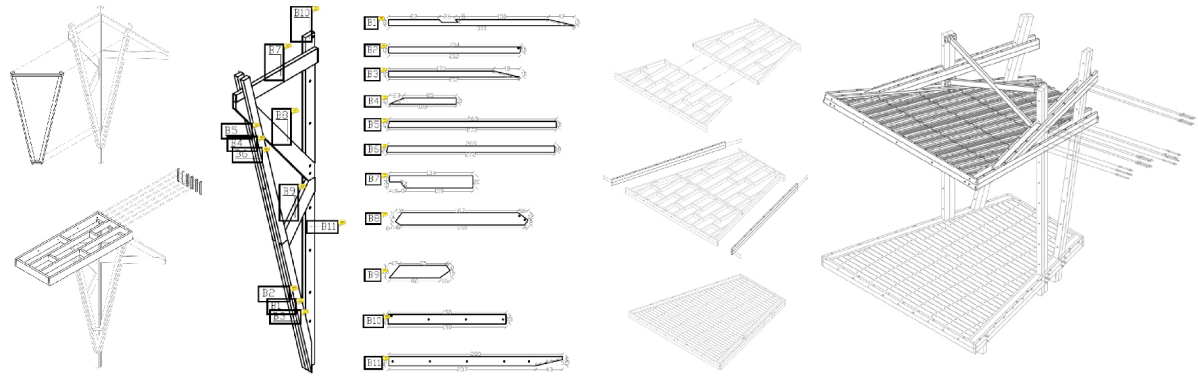


Figure 8: Drawings details prepared as part of the construction booklets: Pier 2 (left) - Modular (right). Source: (Design Studio Students 2023)

The production and assembly of the prototype (Figure 9) were guided by one instructor who acted as a construction leader; hence, the rest of the team followed instructions, helped to solve problems arising from the construction itself, and organized themselves according to their skills' levels for carpentry and power tools manipulation. In some cases, they were also organized according to their physical strength, often required due to the constant assembly & disassembly process. For this reason, students were no longer organized in teams but were constantly reorganized and assigned to different tasks, ranging from problem-solving (e.g., unforeseen connection sequences) to logistics matters (e.g., acquiring screws and bolts).



Figure 9: Construction process of the 1:1 Prototype of the Modular project. Source: (Ecenur Kızılörenli)

3.0 DISCUSSION

3.1. Lessons learned

Studio vs. real project complexities. The design method was structured in a two-phase process, enabling students to develop their design skills by proposing original designs and then acquire specific skills for fabricating such designs by developing scale models and studying assembly/disassembly sequences. Initially, students worked in groups, with each group proposing a design. During the final studio stage, the students submitted a complete architectural project and a set of construction drawings, allowing the pop-up structure to be prepared, built, assembled, and reassembled. In addition, the construction of a prototype at a 1:1 scale provided students with in-depth and real construction knowledge, including managing all associated tasks such as architectural design, construction schedules, documentation, budgeting, communication, and sponsor research.

This structured approach allowed students to transition from conceptual design to practical implementation, providing a comprehensive learning experience that bridges the gap between theoretical knowledge and real-world application. The emphasis on both the theoretical and practical aspects of design and construction enhances students' understanding and prepares them for the challenges of real-world projects.

Studio vs. real project dynamics. The main achievements and learnings of the students revolved around acquiring essential professional features such as teamwork and collaboration, and dealing with materials availability and constraints. Despite inherent difficulties related to teamwork, task division, and information sharing, students grasped the importance of effective communication among team members and the value of using the right tools for a given task to simplify the process. This became particularly evident during the iteration process, where the structure was designed, assembled as 1:10 or 1:5 scale models, and then re-designed until satisfying results were obtained.

The studio provided a dynamic environment that closely mirrored real-world project dynamics, allowing students to navigate challenges similar to those encountered in professional settings. The emphasis on iteration and continuous improvement reflects the iterative nature of design and construction processes in practice. These experiences contribute to the development of practical skills and a mindset that is crucial for success in the professional realm.

3.2. Social engagement

A drawback of remotely preparing the pop-up structure to be built in the village (which was about 1,000 km away) was the limited opportunities for students to engage with the local community during the 15-week studio period. This engagement could have occurred on various levels, including in-depth interviews with the locals, gathering high-precision site measurements for further modelling, and collaborative building with the community for the community's benefit. The only interaction students had with the villagers occurred during the field trip conducted at the beginning of the studio, which, due to budget limitations, was only feasible for a small percentage of the class.

As expected, students who participated in the site trip to the village were more sensitive to the community needs than those who only accessed post-visit information. The main consequence of this difference is reflected in the scale of the proposals: while the modular design, created by students who joined the trip, displayed overall modular dimensions of 3.5 x 3.5 x 4m, the two versions of the pier proposals displayed average heights of 6m. This height and the design complexity of the projects were critical to both the idea of design-for-disassembly and the rural residential scale of the village.

While the studio did not succeed in raising social/earthquake awareness among all students, it did better in drawing attention to the needed recovery efforts in the affected area, especially in the village. A crucial factor in this was the decision to launch a social media account to reach a broader audience, including the local construction industry and other universities. This account regularly provided updates on the studio's efforts, aiming to gain more social visibility, encourage similar initiatives, and potentially secure additional funding for the overall project. Due to time and budget constraints, it remains uncertain whether the local community will perceive the project as a socially beneficial contribution to their everyday lives affected by the earthquake.

3.3 Transferability and shortcomings of the projects

Due to mainly focusing on the constructive aspects of the design proposal, the main shortcoming of the studio was leaving the social aspects of the projects unattended towards the final stages of development. Although both projects had their genesis in responding to community needs, the degree to which either could be more integrated into the local context and responsive to the social needs of the village is uncertain. This is because the simple open modularity-based approach of the Modular, which may offer functional flexibility, may also fail to provide users with closed areas, especially during cold and/or rainy days. Conversely, the semi-modularity features of both versions of the Pier and their site-specific design approaches induced a sense of integration with the immediate context, although the scale of the proposals clashes with the residential scale of the rural context of the village.

3.4 Studio environment

Given the differentiated tasking roles assigned during the semester, the studio environment became dynamic and turned hectic towards the end, especially during the prototype construction (Figure 10). However, the somewhat natural separation of the studio spaces according to different projects and teams mirrored a more profound division rooted in the disappointment of those teams whose designs were not selected for construction. Although all teams had been thoroughly informed that only one project would be further developed towards actual construction—the prototype, some students experienced serious difficulties dealing with their frustration and lack of motivation after the selected project was announced.

Apart from the natural difficulties of teamwork, perhaps one of the reasons for this division was the idea of a studio competition, implicitly put in place at the beginning of the studio. Such an initial competitive atmosphere, which aimed at expediting the selection of a single project for construction, damaged social relationships within the class at an early stage, leading to the creation of a hostile environment. According to (Canizaro 2012), such attitudes are inherent to the challenges associated with design-build programs. In this case, this unfortunate situation not only reflected the fragile condition of some team members' egos but openly conflicted with the social intentions of the projects. Despite being a social aid project intended to help people repair their traumas and regain hope, some students found it challenging to divert their thoughts from their own conditions and ego-based concerns.



Figure 10: Studio environment during the initial phases (left) and at the last stages of the projects (right). There, the studio is used for both designing and construction, while additional workshop facilities were used for model making. Source: (Ö. C. Bakan)

CONCLUSION

This paper proposes a didactic attempt to cover the entire process of materializing an architectural work within an academic semester, and whose outcome helps to palliate the urgent post-disaster social needs of a small community. The proposed hands-on and embedded teaching format focused on pop-up architectural design explorations, following design-for-disassembly principles, ensured students' in-depth learning of construction techniques, detailing, and managing a project. Due to time and material limitations, however, not all students benefited from the possibility of building their own designs, leading to a sometimes-estranged studio environment.

By balancing the benefits and shortcomings of the presented teaching approach, two suggestions are proposed for an enhanced version of the design-build studio of a nature similar to the one described here:

- During the selection process, explore several sites to understand potential benefits, such as accessibility, availability of additional construction space, and potential drawbacks, including topography and property availability. This varied set of options would diversify the responses, especially at early stages and will make proposals more responsive to site-related features.
- During the development stage, explore cross or interdisciplinary collaborations to enrich the technical nature of the building construction solutions. For example, structural/service engineering students could also engage with architecture students during the design definitions of the proposals

Finally, an extended study version of this experimental studio should consider interviewing the students. Due to time constraints, the students' voice is missing in this paper.

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Planetary Boundaries As A Framework For Course Development: What Does It Take To Design For Absolute Sustainability?

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ABSTRACT: The Stockholm Resilience Center has been developing data to help outline a safe space for human activities for a decade. This includes the activity of producing building materials, constructing and operating buildings, which is one of the most significant contributors to greenhouse gas emissions. The impact categories assessed by the worldwide scientific community at the Stockholm Resilience Center match the categories in the ISO standard LCA. This effort is also an expression of the Paris Agreement, which outlines the CO2 reduction each nation must achieve by 2030 to keep the temperature rise on the planet below 2.0- or 1.5 degrees C (UNFCCC 2016). Based on this, a team of universities and industry partners examined what it would take for the Danish construction sector to comply. One of the universities in the project described above took the initiative to develop an interdisciplinary course to investigate the necessary set-up to teach how to design buildings whose environmental impact is within planetary boundaries. The article describes the development process and the results of the first test run of the course in the summer of 2023. The course content is explained based on the discussions between the three educational institutions involved in the development and the pre- and post-evaluation of the 26 participating students, as well as semi-structured interviews with the students. The challenge in course development was whether it was even possible to design for and build within the planetary boundary and how to address this open question in a course design. The ideas and reasoning behind these course design decisions, as well as the results from the pilot course, are presented and discussed in the article.

KEYWORDS: Sustainability, Planetary boundaries, Absolute Sustainability, Life Cycle Assessment, Integrated Design

INTRODUCTION

The international platform Earth Overshoot Day shows that Denmark consumes environmental resources equivalent to four Earth-like planets (Global Footprint Network 2024). Our consumption is so high that the Earth's ecosystems cannot keep up. Therefore, we live today with an imminent danger of, among other things, irreversible climate change that will have enormous consequences documented most clearly by the Stockholm Resilience Center (Figure 1). Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes up to 2100 and this data also derive greenhouse gas emissions scenarios with different climate policies (Figure 2).

Together they draw the contours of a space of solution, but how is this translated into a design process of housing? The construction sector is responsible for 39% of all energy-related CO2 worldwide (WorldGBC 2019) and is also a significant consumer of scarce natural resources such as sand, metals and wood. Therefore, it is crucial for the planet's future that the environmental impact of construction is significantly reduced. This was the motivation for Aarhus School of Architecture, VIA University College and Aarhus University to invite students interested in architecture, building science, civil engineering, and architectural technology and construction management who have completed at least the 3rd semester to apply for a 2-week masterclass course on the topic: How do we design buildings within the planetary boundaries?

Participation in this masterclass allowed students to expand their professional network and gain the latest new knowledge and sought-after skills, such as preparing environmental life cycle assessments, considering planetary boundaries (Figure 1), absolute sustainability, solution spaces for ambitious sustainability requirements, etc.

In terms of research, the course was an experiment in design processes. It was about discovering if it is possible to design homes within planetary boundaries, choosing strategies, calculating the impact and consumption of the choices made, and integrating them into the design processes to keep track. The topics were 1) Building within planetary boundaries and absolute sustainability, 2) Sustainability, ethics and aesthetics, 3) Interdisciplinary collaboration and co-creation, and 4) Introduction to technology for assessing the building's climate footprint in the early design phase. The goal of the masterclass participants was to gain knowledge, skills and competencies about: 4) Planetary boundaries and their significance for the building sector, 5) Application and interpretation of LCA analyses, 6) Interaction between materials, energy and indoor climate, 6) Software for calculation: LCAByg and ICEbear, 7) Development of interdisciplinary building technology solutions.

1.0 METHOD

1.1 Pedagogical and didactic considerations

The three educational institutions involved all address construction but from very different starting points, which were explored and manifested in the course. Aarhus University's Department of Civil and Architectural Engineering has a classic research-based approach to technical-scientific academic subjects and education. VIA is a professional bachelor's degree focusing on architectural technology and construction management. Aarhus School of Architecture is a 5-year beaux-arts, artistic education. The course development's basis was the question: Is creating a design process ensuring the final building stays within planetary boundaries possible? What would such a design process be like - what information and tools are needed?

The course developers from the three institutions took a starting point in research and educational development from the field of Integrated Design (Löhnert, Dalkowski, and Sutter 2003). It is rooted in the 1960s rejection of Fordism's fragmentation into separate work processes on an assembly line. Instead, the idea is based on, among others, Kurt Lewin's research at MIT in group dynamics, where an organization should consist of autonomous interdisciplinary units that can regulate and solve problems themselves (Reason and Bradbury 2008). Anne Grete Hestnes (2008), professor at NTNU, led a European research effort under IEA task 23 on integrated energy design processes (NREL 2003), focusing on informing decisions in complex and dilemma-filled areas of building energy and indoor climate (Hestnes 2008). Integrated design as a project management framework has succeeded and is partly mainstream in the Nordic construction industry, where it is implemented and supported by government-developed freeware, and integrated into building legislation. The basic idea is inspired by the Macleamy curve (MacLeamy 2020) (or, more rightfully, the Paulsons curve (1976)) where the hypothesis is that by focusing time and money at the beginning of the design phase to inform decisions maximally, the building energy performance can be radically reduced via passive measures (window-facade ratio, geometry, orientation, utilization of natural ventilation, passive solar heating, thermal mass etc.).

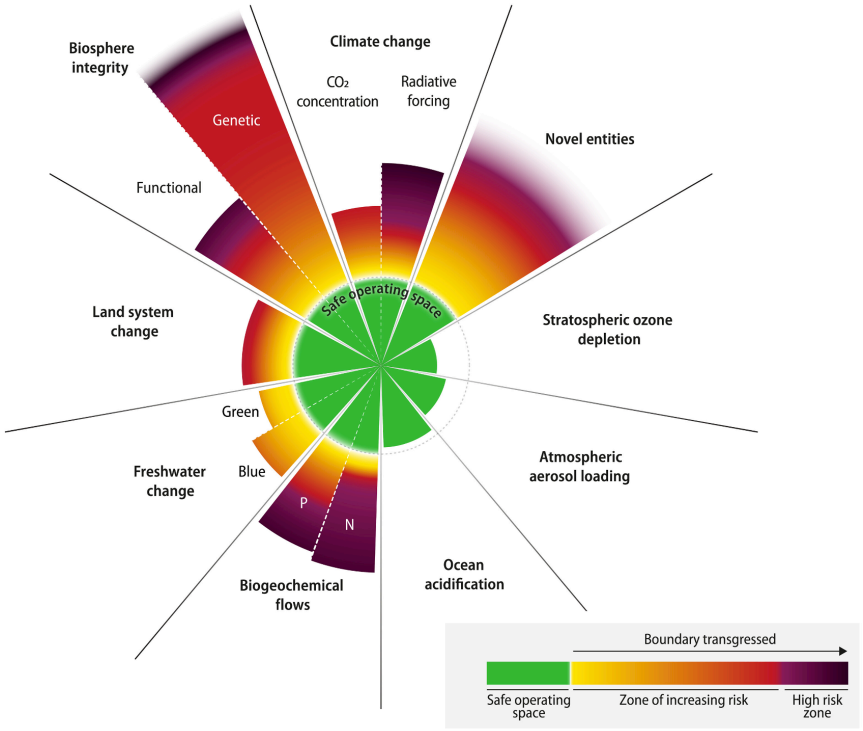


Figure 1: Diagram of safe and just earth system boundaries. Source: (Rockström et al. 2023)

Designing within planetary boundaries is even more complex and dilemmatic than creating 'low-energy' buildings with 'passive' measures, mainly because it requires a strong focus on the whole life-cycle environmental performance of the building. Still, the genericness of establishing a knowledge common ground and working in interdisciplinary teams drawn from the research field of integrated design was chosen as the fundamental approach to the design process. LCA (Life Cycle Assessment) is a meta-method developed in the early 1960s that quantifies the environmental impact of processes. LCA for buildings has developed significantly over the past 10 years with the establishment of international standards for methodology, building product EPDs (Environmental Product Declarations), generic databases for building materials (Ecoinvent 2024; Ökobaudat 2018), government-funded software (e.g., LCAbyg) and implementation in building legislation. From January 1, 2023, it became mandatory in Denmark to document the climate footprint of new buildings via LCA. LCA as a meta-method thus also includes the parts that were included in the IEA task 23 integrated design process of the time, where the focus was on energy and indoor climate. Common to the integrated design processes of the 2000s and the complexity of the planetary boundaries is that it is through fast and visualizing software that provides access to simulations and quantifications that an ongoing design process can be informed with the knowledge that can help achieve the goal (creating

buildings that are within the planetary boundaries). The course introduced and used a range of software, as described below.

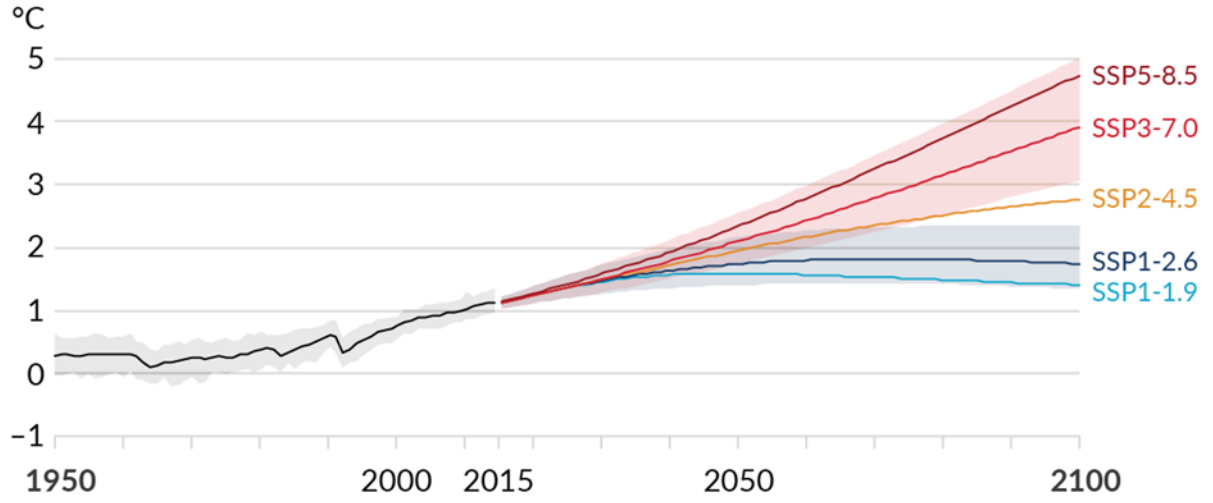


Figure 2: Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies. Source: This figure is a reproduction of Figure SPM.8 from the IPCC 6th Assessment Report WGI Summary for Policy Makers, Source: (Press Office 2023).

A scientific basis for the course development was Aarhus University's research into the impact of housing on the planetary boundaries. Based on this research, it is possible to develop a calculation method that can be used in a design process to establish a CO2 budget for the building function 'dwelling' that respects the planetary boundaries. In preparation for the course, based on the methodology, a simplified version was further developed in a spreadsheet that the course students were taught to use. The principle and the spreadsheet are described in more detail below.

A beaux-arts academy operates within what Michael Polanyi called 'tacit knowledge' (Polanyi 2009). The ability to bring together several completely different parameters in a site-specific architectural expression is developed in a practice setting, practiced through guidance, described by Donald Schön (1983), among others. Schön synthesizes his observation of the architect's actual design practice: -Making previous experience fit the unique situation - experimenting and testing hypotheses through Virtual (visualized) worlds (Schön 1983). This 'practice situation between teachers and designing students was integrated into the framework for the afternoon teamwork, where professional architects, engineers and LCA practitioners actively entered the design processes but followed the students' lead.

Didactically, it became apparent during the planning process that all involved institutions used problem or project-based learning (Pettersen 2001). Therefore, it was decided that this, together with the ideas from 'integrated design', would be a guiding principle for the organization of the entire course. A didactic relational model by Hiim and Hippe (Hippe and Hiim 2007; 2005) was used as a dialogic framework in the research group's course planning. The model consists of six factors that educators should consider: Learning assumptions, framework factors, objectives, content, the learning process and assessment (Hippe and Hiim 2007). One of the strengths of this model is the absence of hierarchy among the factors, so all factors influence and are influenced by each other, allowing for an iterative process during the planning and decision-making processes. All six factors were discussed and considered, but some became more important than others. For example, establishing common learning goals and objectives was one of the most significant factors when choosing the content that each institution presented. Consideration was given to what knowledge and skills the students already have and what would be appropriate learning content that a) brings new knowledge and is not repetitive, and b) is not too distant for students from the other institutions to understand and work with. Living up to both principles proved difficult as the students from the different institutions had different prior knowledge and skills. At the same time, it was necessary to establish some common basic level of knowledge and skills for all students to empower and prepare them for the course challenges and learning exposure ahead. Therefore, repeated content was accepted by the institutions' students, thus attempting to establish a common ground for students' knowledge level, while invited external lecturers would deliver new knowledge, and all students would be able to understand and work with the new information.

2.0 RESULTS

2.1. Creating a radical common ground

Based on a year of development work (described above), the course was organized so that half of the teaching time was used to create a professional common ground, which was a radical choice. The lecturers divided the students into interdisciplinary design teams (5 people), and a design task was set: a home for two adults and two children that respects the planetary boundaries of Denmark. Each day started in plenary with speakers (invited and

internal), followed by training on the chosen topics (LCA, energy and indoor climate, 'the good but few m^{2}'). In the afternoon, the design teams focused on the project. After the first week, there was a mid-term critique with invited critics from the construction industry. Calculations and designs were presented to the same invited critics on the last day.

Table 1: Two-week course plan. Source: (Authors 2024)

Week 1	Monday	Tuesday	Wednesday	Thursday	Friday
Theme	Planetary boundaries	LCA and square meters; *Flexible, creative and long-lasting buildings*	LCA and materials	LCA and energy; *Energy in the future*	Pitch and discussion
Content	• Welcome • Sustainability and planetary boundaries • How will we live when the sustainability crisis is solved?	• What does it take to feel rich on a few square metres? • What is the sustainability in around-the-clock functions and flexibility?	• Introduction • Background • Norm and legislation • LCAByg (LCAbyg 2023) • EPD	• Energy and indoor climate • ICEBear • BE18 (SBI 2024)	• Idea pitches • Discussion about the future of the professions considering the climate crisis
Student activities	Icebreaker, planning of the upcoming weeks, debates of today's lessons	What are the good square metres? Portfolio reflections, and development of basic concepts	Portfolio reflections, basic considerations for the choice of materials based on the LCA and EPD	Portfolio reflections, considerations about the energy sources, energy calculations and considerations about the indoor climate	

Week 2	Monday	Tuesday	Wednesday	Thursday	Friday
Theme	LCA and circular economy; *Tectonics of reuse and transformation*	LCA and biomaterials	LCA and design process	Lesson free day reserved for project work	Final pitch
Content	• LCA concerning phases C and D • Reuse of buildings and/or materials	• Biodiversity and construction techniques • Biomaterials and different scenarios in phase C and D	• LCA as a design and decision-making tool • What does LCA tell us, and what does it not tell us?		
Student activities	Portfolio reflections, considerations about a deeper LCA strategy with focus on phase C and D	Portfolio reflections, further development of concepts	Portfolio reflections, critical debate of the LCA as a method, further concept developments		

2.2. Architecture

Architects often handle the earlier design phases (geometry, window-facade ratio, orientation), and integrated design research has proven to significantly impact energy, indoor climate, and, thus, environmental impact. There is, of course, the overarching consideration that if a building has aesthetic qualities, users will be interested in maintaining and taking good care of the building. In a sense, this will result in a form of 'avoided new construction' because it extends the lifespan of the building. In this sense, good architecture is essential to 'staying within planetary boundaries', but it is difficult to operationalize in a multidisciplinary design team. It is the overall goal, so to speak, while more concrete sub-goals are needed in an incremental design collaboration. That is why we chose to focus on 'few m^{2}' as a theme.

A research result from Aarhus University showed that if the assumption is that the environmental impact from materials and building operation of buildings in general is reduced by 84%, then 20 m2 per person would be at the planetary boundary. This should be contrasted with 54 m2 per person (Statistics Denmark 2024) – the average in Denmark today. Large homes have always been a sign of social ambition. Therefore, the size of buildings, understood as m2 of housing per person, is central to the basic equation behind LCA: Impact = population growth x affluence x technological development. I=PxAxT (Hauschild, 2018).

A key element of architectural quality is whether the user experiences feeling happy, wealthy, dignified, safe, proud and delighted with their surroundings. These qualities have to do with whether the user of a building experiences themselves as living in surroundings that provide the experience of affluence (the 'A' in the IPAT equation). Therefore, it was decided that the School of Architecture's teaching should focus on architectural strategies to achieve the quality of 'affluence' with minimal environmental impact on very few m^2 per person. The architectural profession has a vast repertoire of strategies that create a sense of wealth; the Palace of Versailles: sumptuous materials (glass, mirrors, gold), high ceilings, large rooms, views over large parklands, symmetry, lavish and ornamental details, etc. The goal was to learn how to 'filter' architectural strategies that give the experience of affluence, but do so in a way that does not require a Palace of Versailles. They can be summarized in the following categories:

- Creativity in m2 programming (using the same spaces for multiple functions and using design thinking to question functional needs).
- Movable multifunctional architectural elements
- Sharing with others, so it does not have to be included in every home.
- Close to nature and 'protected' outdoor spaces (the m2 with the least CO2 emissions are in the natural climate - gardens, urban spaces, parks).

The results of the 'feeling affluent in a few m2' approach could be seen in the projects of the interdisciplinary teams. For example, one team worked with the strategy of placing 2-3 families in 1960s detached houses, where today, often only 2 elderly live. However, affluence was achieved by intertwining the gardens into park-like landscapes that the homes opened up to and by ensuring that each family had large spaces in their homes because functions like laundry and utility rooms could be shared. Others worked on the experience of affluence by having large, high-ceilinged multifunctional spaces where 'functions' such as sleep/rest were established in spatial 'super furniture' that gave way to large, bright spaces with access to nature. Staying in unheated garden spaces expanded the possibilities for users without increasing the number of m2 built, which were features explored by several teams.

2.3. Building science

The involved researcher and lecturer from Aarhus University presented a concept of the planetary boundaries and how current Danish buildings perform using the limit for annual emissions of CO2 equivalents globally allocated to the function of 'dwelling' as described in the paper by Brejnrod et al., (2017) to the students. Furthermore, a generic method for allocating the globally allowed annual emissions of CO2 equivalents with respect to the planetary boundaries to the function of 'dwelling' was presented together with a spreadsheet where the method was implemented (Figure 3). This spreadsheet is intended to enable the students to discuss moving from a global budget that respects the planetary boundaries to a budget for the function of 'dwelling' in Denmark. The students, therefore, had to discuss the magnitude of the global budget, which may vary depending on the method applied to calculate it (Petersen, Ryberg, and Birkved 2022) and how to deal with the trajectory of the global population, which may increase or decrease the personal budget depending on what growth scenarios is chosen. Next, they had to consider how much of a personal budget is fair to allocate to the function of 'dwelling' and whether there are some social reasons to differentiate the personal budget depending on, e.g. geographic location, historical considerations, equality versus equity, etc. Finally, the students could generate a budget for their project's annual emission of CO2 equivalents, which depends on how many people the building will be designed for. This budget could be 'per year' or 'per m2 heated living area per year'; in case the latter, the budget would be dynamic depending on how many people per m2 the students were designing for. The budget described above was the benchmark for the outcome of the LCA conducted for the building design of the students (see section 2.4).

The students were also presented with a building performance simulation tool named ICEbear (Lauridsen, Petersen, and Purup 2014) that can be connected to geometric models made in SketchUp, Rhinoceros/Grasshopper, and REVIT. ICEbear can perform integrated hourly simulations of the indoor operative temperature, air quality, daylight, and corresponding energy needed for the chosen geometry in any climate using only a few user inputs. This tool enabled the students to consider thermal comfort, daylight conditions, and energy needs while proposing building designs. The calculated energy need was the input to the B6 phase in the LCA calculation (see section 2.4).

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Variabel i formel**	**Enhed**	**Værdi**		**Note**							
2	SoS_global	kg CO2-ækv/år	2,51E+12		Scenario AR+(95%) i ref. https://arxiv.org/abs/2209.00118							
3	P_global	Antal personer	8223573750		Egalitaristisk fordeling af jordens budget (FN befolkningsstatistik, 95% fraktil for 2025)							
4												
5	Alpha	-	0,215		Forsøg på utilitaristisk fordeling ved brug af Europæisk COICOP (fx er 0.215 alfa for det "at bo")							
6	Beta	-	1		Politisk faktor, der omfordeler SoS af den ene eller anden grund							
7												
8	P_byg	Antal personer	4		Antal personer, der har andel i bygningen							
9	A_byg	m2	110		Hvor mange m2 vil man bygge?							
10												
11	**Safe Operating Space**	kg CO2-ækv/m2/år	**2,4**		Safe operating space for bygningen							
12	**Safe Operating Space**	kg CO2-ækv/år	**262**		Safe operating space for bygningen							
13												
14												
15	$SoS_{byg} = \frac{SoS_{global}}{P_{global}} \cdot \alpha_{byg} \cdot \frac{1}{A_{byg}} \cdot P_{byg} \cdot \beta$										$[kgCO_2eq/m^2/år]$	
16												
17												

Figure 3: Screenshot of the spreadsheet developed to operationalize the principal discussion on allocating the globally allowed annual emissions of CO2 equivalents with respect to the planetary boundaries to buildings – in this case, the function of 'dwelling'. Source: (Steffen Petersen 2024)

2.4. Life Cycle Assessment

The choice of building materials has a significant impact on the overall environmental impact of a building and is closely linked to the technical execution of the construction. The two areas - material selection and assumptions for passive energy and indoor climate solutions, as well as the number of m2 inflict environmental impacts- are demonstrated in an LCA. LCA is thus the most central field in the course. VIA UC organized the LCA workshop. The content consisted of two parts: A) a presentation of the background, legislation, norms, theory and methodology of LCA, and B) an introduction to LCAByg software.

Part A was based on current legislation, EN15978, which is a standard for the Assessment of environmental performance of buildings. Part B, LCAByg, is a free software tool developed by BUILD, part of Aalborg University. LCAByg is used to calculate LCA for buildings and is adapted to Danish national legislation and practice for LCA calculations. Although there are several tools for LCA calculation, each with varying complexity, LCAByg was chosen primarily based on previous teaching experience. Its ease of use, especially for beginners, became apparent through interactions with students, which is a crucial aspect due to the limited time the students had to learn and use the software as part of the assignment. The software is also not fully automated, requiring users to understand the LCA process and enter variables such as quantities, environmental data and material selection. This semi-manual approach encourages a better understanding and reflection on the LCA methodology.

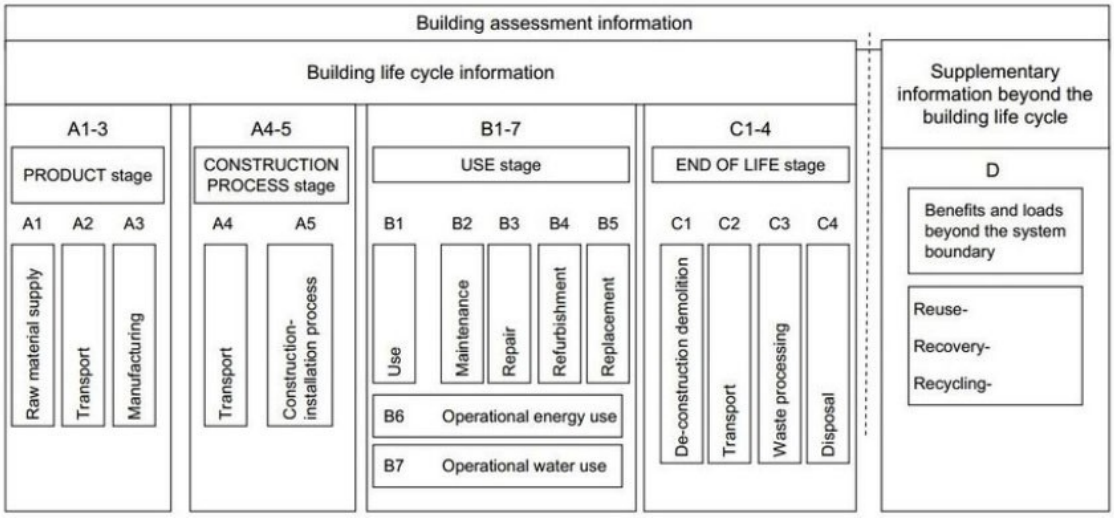


Figure 4: Building's LCA stages according to EN 15978. Source: (DS/EN 15978:2012. Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method (2012).)

The workshop content was presented through a dynamic interaction that combined several short presentations (approx. 10-15 minutes) of the first part (A) with hands-on engagement using LCAByg. In addition, small group discussions on the presented content and dilemmas were also facilitated, e.g., concerning the impact of different 'energy futures' for Denmark. This teaching approach accommodates different learning styles with inspiration from Kolb (1983) and Illeris (2015), emphasizing the importance of an active learner to support the learning process. As an educator, it is almost impossible to know each student's preferred learning style, and therefore, the presentation strategy was aimed at creating learning activities that could provide different learning preferences according to the theory of learning styles (Kolb 1983; Illeris 2015).

2.5. Pre and post evaluation

Pre- and post-evaluations were conducted via digital questionnaires and focus group interviews before and after the course. During the pre-course focus interview, it came forth that the students placed more emphasis on biodiversity than the course planners had anticipated, and 4 hours of consultancy concerning biodiversity impacts from design proposals were integrated into the final course planning. Many wanted to learn about LCA, and though 60% had never worked with it before, the post-evaluation showed that 100% could conduct a simple LCA. According to the post-evaluations, many wanted to learn about energy and indoor climate but did not learn it to the same extent.

A majority in the pre-evaluations described their motivation for taking the course as driven by ethics, but this changed in the post-evaluations, showing that more people moved towards the course design processes and the goal of planetary boundaries could lead to an exciting working life, and this could be a 'driver'. In the final evaluation, only 10% saw ethics as a central 'driver'compared to 58% before the course started, the pre-evaluation. It could be interpreted in that way that the course gave the students concrete tools and methods that made it operational to design buildings that would stay within the planetary boundaries. In this sense, a new design practice was outlined. In the final evaluation, 70% rated 'changing people 's mindset' as the most important element in reaching the goal of staying within planetary boundaries, compared to 73% in the pre-evaluation. So, this aspect did not move during the course.

CONCLUSION

Staying within the planetary boundaries

Despite the availability of cutting-edge design processes and matching software, it is very difficult to establish processes that lead to construction within planetary boundaries. The students' projects came close to reaching the goal, but no one could meet the target of staying within the planetary boundaries in their design for a dwelling for 2 adults and two children. There are two factors responsible for this: firstly, the Danish rules for LCA in construction dictate that biogenic building materials must be calculated to be incinerated after 50 years, though a large number of historical buildings demonstrate that this will not actually be the case for biogenic materials in the interior (Andersen, Jensen, and Ryberg 2022).

Secondly, the students were very concerned with designing solutions with broad appeal. They deliberately sought a 'common' expression that would be acceptable to many. There was an ethical choice in this, informed by numbers that illustrate the scale and speed of the total transformation needed to adequately address the biodiversity and climate crisis. In addition, the interdisciplinary aspect of the groups and the appeal of influential keynote speakers also meant that the projects were not as extreme in terms of design as the situation might require. It could be seen as a result that even if the dwelling is based on reuse and transformation with only very little added new (and biogenic) material, with a maximum effort for reducing energy use, it is not possible in a Danish context to match familiar imagery of what a family home should look like in size and form. The closest project had a smaller amount of m2 (a third of what is usually allocated in Denmark), and included radical proposals concerning sharing and inside-outside climate boundaries.

The radical educational choice to use so much of the time to establish a truly interdisciplinary common ground was a surprising success. No students complained of low learning on the days when 'their' discipline was taught to the others. On the contrary, the evaluations emphasized that new perspectives on their discipline were necessary. According to the pre-evaluations, LCA is central and a significant motivation for taking the course. That wish was fulfilled. Two surprises emerged when comparing pre- and post-evaluations: the primarily ethical motivation during the course was replaced by a realization that working with planetary boundaries can lead to an exciting working life. This was probably due to the support from the industry that participated in the critics, but also because reaching the planetary boundaries went from being abstract to being given a path and software to document the distance from the goals. Surprisingly, there was no move during the course to consider a 'change in general mindset' to be more important than 'quantifying environmental impact'. It stayed the same.

Next iteration and afterthoughts

As mentioned, the course was the first iteration. In further development, some feedback the students gave in the evaluations will be integrated, e.g., the professional common ground can be more precise if there is a daily upload of exercise material and design material. The architectural workshop can be developed with precise and specific 1-hour 'exercises' that get team members to explore the design strategies both individually and as a team, and it must be made clear earlier how radically different the space of solution must be. In other words, it is not what looks like known, that leads to the goal. Integrating biodiversity regeneration in a quantifiable way, not just as a reflection, is also a concern, and direct reuse of existing structures is a priority.

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The Effects of Passive Design on Indoor Thermal Comfort and Energy Savings for Residential Buildings in Hot Climates: A Systematic Review

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ABSTRACT: In this study, a systematic review and meta-analysis were conducted to identify, categorize, and investigate the effectiveness of passive cooling strategies (PCSs) for residential buildings. Forty-two studies published between 2000 and 2021 were reviewed; they examined the effects of PCSs on indoor temperature decrease, cooling load reduction, energy savings, and thermal comfort hour extension. In total, 30 passive strategies were identified and classified into three categories: design approach, building envelope, and passive cooling system. The review found that using various passive strategies can achieve, on average, (i) an indoor temperature decrease of 2.2°C, (ii) a cooling load reduction of 31%, (iii) energy savings of 29%, and (v) a thermal comfort hour extension of 23%. Moreover, the five most effective passive strategies were identified as well as the differences between hot and dry climates and hot and humid climates.

KEYWORDS: passive design, residential building, energy saving, indoor thermal comfort, hot climates

INTRODUCTION

Traditional buildings in hot climates have long used passive design strategies to maintain comfortable indoor temperatures, a practice predating modern air conditioning (AC). These strategies are favored in low-energy buildings to minimize heating and cooling loads. However, there's a global trend towards mechanical AC, with its advent in the early 20th century and mass adoption in the 1950s in the U.S., where now 90% of homes have AC. In contrast, Europe has less than 10% AC penetration. AC adoption is surging in developing nations like China and India. As climate change exacerbates heat extremes, reliance on AC is expected to grow, evidenced by the tripling of global AC sales from 1990 to 2016. (IEA 2018)

Over-reliance on air-conditioning systems presents three significant issues. Firstly, it leads to a surge in energy use, as cooling systems currently draw about 20% of global electricity, contributing to 8% of energy consumption in U.S. homes. This trend may escalate global energy demand and related carbon emissions. Secondly, the heavy reliance on air-conditioning strains power grids, especially during heatwaves in developing nations, risking power outages when demand exceeds supply. Finally, there's an issue of environmental injustice; climate change intensifies weather extremes, impacting disproportionately on marginalized groups. Heatwaves, now the deadliest weather phenomenon, afflict the elderly, young, pregnant women, and those with certain medical conditions or socioeconomic disadvantages the hardest, across both affluent and cooler regions.(Kravchenko et al. 2013; Zuo et al. 2015).

To adapt to more frequent and intensified heatwaves caused by climate change while minimizing energy consumption increases and accounting for potential power outages, the application of passive design strategies is critical to prepare existing and new residential buildings. Passive strategies do not all result in energy use during the operation, and most passive strategies are low-cost or at no cost, which are practical techniques for use by low-income communities in hot climates. However, because of the over-dependency on mechanical air-conditioning systems in developed countries, such as the United States, knowledge of applying passive design strategies has gradually diminished. In some areas of the world, people still apply passive strategies inherited from their ancestors, but passive strategies are generally becoming obsolete due to a lack of guidance and requirements in building codes and regulations. For example, Akande (2010) it is indicated that apartment design in Nigeria is not generally responsive to the local climate; therefore, dependence on electrical ventilation is common in all apartments. Further, frequent power outages, sometimes over six hours a day, have created tremendous heat stress in urban dwellers' lives.

Moreover, although passive design strategies have been accepted as a rule of thumb or ancient wisdom, there is a limited understanding of the types of strategies available and their associated quantifiable thermal improvement or energy-saving benefits. The omission of applying passive design is partially due to insufficient evidence of the effectiveness of passive strategies, especially for thermal comfort. There are a few reviews published on the energy-saving potential of applying passive cooling strategies. For example, Friess & Rakhshan, (2017) reviewed over twenty studies conducted in United Arab Emirates (UAE), they concluded that the building envelope passive strategies (e.g., window-to-wall ratio) have the potential to significantly reduce the overall energy use in UAE. Another review was conducted for Malaysia on the effectiveness of building envelope design on energy consumption of high-rise buildings. Moreover, most existing review papers focused on specific climate regions defined by geographical boundaries because applicable passive cooling strategies vary significantly per climatic

conditions (i.e., hot and humid vs hot and dry). On the same line, the passive strategies used in cold climate are often not applicable to hot climatic condition. To date, there is limited global review looking into all hot climate and providing findings that can generalized. A thorough understanding of passive cooling strategies (PCSs) for residential buildings in hot climates is critical for providing empirical evidence and guidelines for applying passive cooling techniques in future projects.

The goal of this paper is to review recent progress in assessing and measuring passive cooling effects related to indoor heat exposure mitigation through reducing the indoor temperature and cooling load demand. The effects can also be measured in energy savings and comfort hour extension. More specifically, in this systematic review and meta-analysis, the author aims to provide evidence to answer the following research questions:

1. What PCSs have been used in residential buildings in different hot climates?
2. What measurements have been used to quantify the benefits of PCSs?
3. What evidence has been found of applying passive strategies in a residential context?

1.0 METHOD AND MATERIALS

1.1. Literature review

A systematic review approach was used to extract information published in the last several decades on the effectiveness of passive design strategies in buildings, with a focus on residential buildings. This approach was initially used in the field of medicine (Askie and Offringa 2015); now it is common in other disciplines, including construction management (Ayodele, Chang-Richards, and González 2020) and the built environment (Pomponi et al. 2016). Compared to a conventional literature review, a systematic review uses a systematic and documented process for screening, selecting, and synthesizing the literature for inclusion in the review (Askie and Offringa 2015). It is valuable in providing a reliable evaluation and synergy of previous literature from which researchers can draw conclusions, identify knowledge gaps, and make informative decisions (Rañeses et al. 2021). A systematic review uses a methodical scheme, from identifying the issue and determining the question to forming the review protocol, including predefined eligibility criteria for studies. Its purpose is to minimize bias and provide more reliable findings (Askie and Offringa 2015).

A protocol for this study was developed based on the preferred reporting items for systematic review and meta-analysis (PRISMA) protocol guidelines (Shamseer et al. 2015). It comprises several stages: (a) identify the publications, (b) screen the publications, (c) assess the eligibility of the publications based on predefined criteria, and (4) conduct the synthesis and meta-analysis.

The databases Web of Science, ProQuest, and PubMed were used. The following search terms and similar words were used in the initial identification of publications:

- Passive strategies: Passive cooling, Passive design, Hot climate-sensitive, Natural ventilation, Evaporation cooling, Thermal cooling, Building Orientation
- Building: Residential building, House

The publications included were selected based on the following criteria: (i) the study addressed indoor thermal comfort and passive strategies as the main research topic; (ii) the study relied on empirical data (on-site measurement or simulation) to draw a conclusion; (iii) the study specified passive design variables and their measurement unit, with quantified effectiveness either measured in temperature decrease or energy savings; and (iv) the study focused on low-cost passive design (double skin façade was excluded).

As illustrated in Figure 1, initially, a total of 339 publications were identified from Web of Science (n=231), ProQuest (n=72), and PubMed (n=36). The disciplines and fields included epidemiology, environmental health, environmental science, construction, engineering, and architecture. Among the three data sets, 92 publications overlapped, resulting in 247 identified articles. To narrow down the publications, we conducted the initial screening by reading through the abstract of all founded articles. After the abstract screen, 133 publications were selected for full-text eligibility assessment using the abovementioned criteria. After the full-text assessment, 42 articles were included for meta-analysis, synthesis, and conclusion-building.

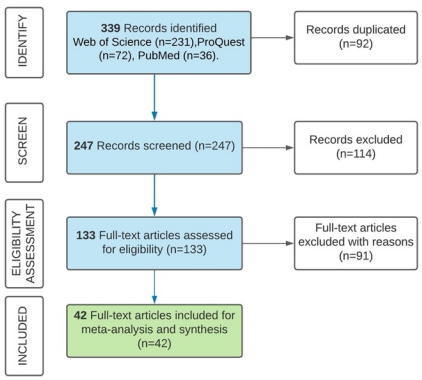


Figure 1: Flowchart of the review process Source: (Author 2023)

1.2. Meta-analysis

Unlike a systematic review, a meta-analysis is a statistical synthesis of the results of previous studies that similarly addressed a related hypothesis (Ganeshkumar and Gopalakrishnan 2013). Simply put, a meta-analysis is a statistical procedure for combining data from multiple studies. Individual studies are usually small and may not directly lead to significant results but may contribute collectively to an outcome or a new body of knowledge. In the building and construction field, meta-analysis is used to study quantitative sustainability methodologies in construction [6] and investigate buildings' embodied energy and carbon (Minunno et al. 2021). However, the use of meta-analysis is limited to sustainable building and passive design. To the authors' knowledge (based on the literature review), no meta-analysis has been conducted yet on the effectiveness of passive design on indoor temperature control and energy savings.

2.0 FINDINGS

2.1. Overall description

A total of 42 studies were included in the final full-text review and meta-analysis, and 30 PCSs were included in the review. The PCSs can be grouped into three categories: design approach (DA), building envelope (BE), and cooling system (CS), as listed in supplement document column six of Table 1.The passive strategies included in the study can be divided into three categories: load reduction, passive solar heating, and passive cooling.

This paper focuses on load reduction and passive cooling. Compared to passive heating, passive cooling is much more dependent on climate. Therefore, the PCSs for a hot and dry climate can differ from those for a hot and humid climate. The strategies for load reduction can be categorized into the overall design approach and building envelope design. There are 30 PCSs included in this review as listed in Table 1. The following sections will provide explanations of primary passive strategies included in this study. The primary passive strategies are those that were studied by more than three publications. The selected PCSs have been grouped into three passive strategy categories: design approach (DA), building envelope (BE), and cooling system (CS).

Table 1: Passive cooling strategies. Source: (Author 2023)

Passive Cooling Strategy	Passive Category	Description	Climatic Condition
PCS 1	DA	Orientation	All
PCS 2	DA	Geometry/form/height	All
PCS 3	DA	Courtyard	All
PCS 4	DA	Roof shape (dome, vault)	All
PCS 5	DA	Sloped roof	Hot and dry
PCS 6	DA	Window-to-ground ratio	All
PCS 7	DA	Patio	Hot and dry
PCS 8	DA	Space utilization	All
PCS 9	BE	Roof property	All
PCS 10	BE	Exterior wall property	All
PCS 11	BE	Interior wall property	All
PCS 12	BE	Glazing/window	All
PCS 13	BE	Replace single glazing with double glazing	All
PCS 14	BE	Overhang projection factor	All
PCS 15	BE	Horizontal shading	All
PCS 16	BE	Vertical shading	All
PCS 17	BE	Window-to-wall ratio	All
PCS 18	BE	Green roof	Hot and dry
PCS 19	BE	Floor/ground thermal property	All
PCS 20	BE	Cool roof	All
PCS 21	BE	Color (or paint) of exterior wall	All
PCS 22	CS	Passive evaporative cooling	All
PCS 23	CS	Natural ventilation	All
PCS 24	CS	Night ventilation	All
PCS 25	CS	Solar chimney	All
PCS 26	CS	Wind catcher	All
PCS 27	CS	Ground-coupling cooling (earth pipe cooling system)	Hot and dry
PCS 28	CS	Water-to-air heat exchanger	Hot and humid
PCS 29	CS	Hydraulic-driven ventilation device	Hot and humid
PCS 30	CS	Earth sheltering (semi-basement)	Hot and humid

2.2. Meta-analysis findings

Four measurements were used to evaluate the effectiveness of PCSs: energy savings (%), cooling load reduction (%), indoor temperature decrease (°c), and indoor thermal comfort hour extension (% of hours). However, not all PCSs had associated quantified measurement units. Yang et al. (2020) conducted field measurements on two vernacular houses to study earth sheltering. The air temperature, relative humidity, globe temperature, air velocity, and wall surface temperature were measured during the summer months at 30-minute intervals. The results showed earth sheltering was the most effective strategy to satisfy human thermal comfort, followed by night ventilation.

However, the data collected only demonstrates a comparison between outdoor and indoor temperatures rather than an indoor temperature decrease between buildings with and without passive strategies. The researchers found that the indoor air temperature in summer was around 31°C, while outdoor temperatures exhibited a diurnal variation of 15.7°C, from 28.6°C to 44.3°C (Yang et al. 2020). The quantified measurements were difficult to include in the meta-analysis; therefore, this study was excluded from the analysis but used as a reference to conclude.

In addition, extrapolating an individual PCS was difficult since many studies that used a simulation method investigated several PCSs together. For example, Liu et al. (2020) simulated five PCSs concurrently (PCS10, PCS12, PCS14, PCS16, and PCS17) using an EnergyPlus model, with results indicating the annual cooling load and peak cooling load can be reduced by 56.7% and 64.5%, respectively. Al-Qahtani & Elgizawi (2020) studied a single-family detached house in Saudi Arabia using a different software called Design Builders, in which PCS10, PCS12, PCS15, and PCS18 were simulated together. They found that the indoor radiant temperature could be decreased by 16%, from 30.8°C to 26.1°C, after applying the PCSs, and that the cooling load could be reduced by 41.12%. Therefore, understanding the PCSs' individual and combined benefits is valuable.

Figure 2 illustrates the applied individual PCSs and associated measurements. The X-axis represents an indoor temperature decrease (°C), and the Y-axis represents a cooling load reduction (%); they are two primary measurements of the effectiveness of passive strategies. The farther right along the X-axis and the higher along the Y-axis, the more effective the PCSs are. The size of the circles and the number in the circle in Figure 2 represent the frequency of those PCSs being studied; for example, the "6" in the PCS15 circle means six publications (studies) include horizontal shading as a PCS. The most studied PCSs are exterior wall (PCS10), glazing/window (PCS12), roof (PCS9), window-to-wall ratio (PCS17), cross ventilation (PCS23), horizontal shading (PCS15), vertical shading (PCS16), orientation (PCS1), and solar chimney (PCS25).

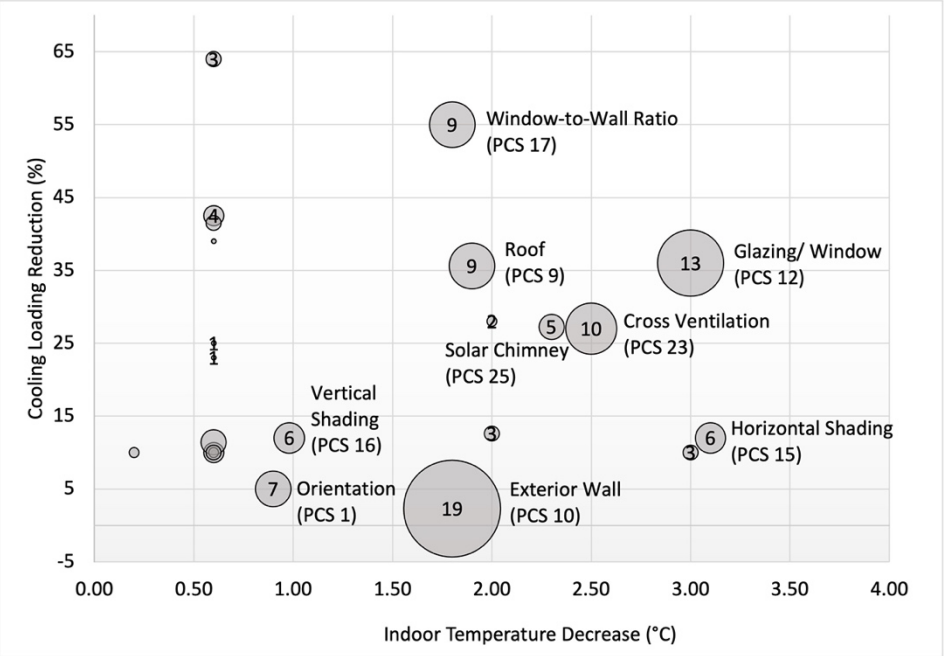


Figure 2: Applied passive cooling strategies and their measurements. Source: (Author 2023)

Two important findings can be drawn from Figure 2. First, the most frequently studied and commonly used PSCs are not necessarily the most effective. For example, PCS10 appeared in 19 publications across five continents, reflecting people's consensus on the importance of the external wall's thermal performance. However, PSC10 has a relatively low indoor temperature decrease, averaging at 1.75°C, compared to that of PCS12 and PCS15. PCS10's cooling reduction effectiveness is also lower than most other PCSs, averaging at 2.30%.

Second, all PCSs related to windows and their solar control are highly effective in reducing temperature and cooling demand. The most effective PCS in cooling reduction is the WWR (PCS17, 55%), and the most effective PCS for indoor temperature decrease is horizontal shading (PCS15, 3.6°C). PCS12 is also effective in a cooling load reduction (36%) and temperature decrease (3°C). These findings support controlling the WWR and adding shading in hot climates and reinforce previous findings from commercial office buildings. For instance, Troup et al. (2019) analyzed the 2012 CBECS (Commercial Buildings Energy Consumption Survey) and found the WWR is a significant predictor of energy use for cooling and, to a lesser extent, lighting and ventilation. However, in hot and dry climates, the optimal WWR (PCS17) was found to be less than 20% (Kaihoul et al. 2021), while in hot and humid climates, the ratio was recommended to be around 20%–24% Yao et al. 2018). Despite these findings, the optimal WWR is rarely used in modern buildings.

2.3. Benefits of applying passive strategies

Figure 3 demonstrates four measurements of the effectiveness of PCSs. Different studies employed varying measurements; therefore, the measurements in publications did not always overlap. This review aims to provide a

better understanding of the effectiveness of passive cooling, thus both individual and combined benefits are included in the analysis. Consequently, a wide range of variations can be observed below. Figure 3a shows 36% of the studies (n=15) used an indoor temperature decrease to demonstrate the benefits of passive strategies, with the decrease varying between 0.2°C and 6.1°C. The highest temperature decrease was achieved in a neo-vernacular three-story apartment building in southern Algeria (Amraoui et al. 2021). The passive strategies applied were PCS1, PCS2, PCS4, PCS10, and PCS15. The project applied traditional techniques to make the exterior bricks (*tufla*) and slabs (*tafza*) while using locally available materials (Amraoui et al. 2021). Another study focused on traditional straw clay housing that used local materials together with passive cool roofs and shading; these low-cost and low-tech buildings can achieve an indoor temperature reduction of 5°C. These findings are encouraging since they demonstrate that low-cost local materials and techniques can achieve thermal comfort in harsh climates, without the use of expensive, advanced materials. They also demonstrate the wealth of techniques that can be learned from traditional and vernacular building design and construction.

The second measurement is the cooling load reduction (refer to Figure 3b), with a median value range between 18.1% and 63%. The highest reduction reported was 65%, from a study conducted on Moroccan mid-rise apartment buildings. The results were from a simulation rather than on-site measurements, and the passive strategies tested were PCS1, PCS11, PCS12, and PCS17 (Abdou et al. 2021). The lowest reduction was found in an Algerian study on low-rise single-family detached and attached houses, which represent 20% of the residential sector in southern Algeria (Kaihoul et al. 2021). The research team studied several scenarios with different strategies, including PCS1, PCS11, PCS12, PCS15, PCS16, and PCS17. They found that adding external shading produced the lowest impact, reducing the cooling load by only 0.9%, possibly because the studied buildings already had deep recessed windows with a self-shading effects adding additional shading generated a negligible effect. In addition, this study indicated that an increased WWR, from 20% to 40%, can increase the cooling load by 15.96%.

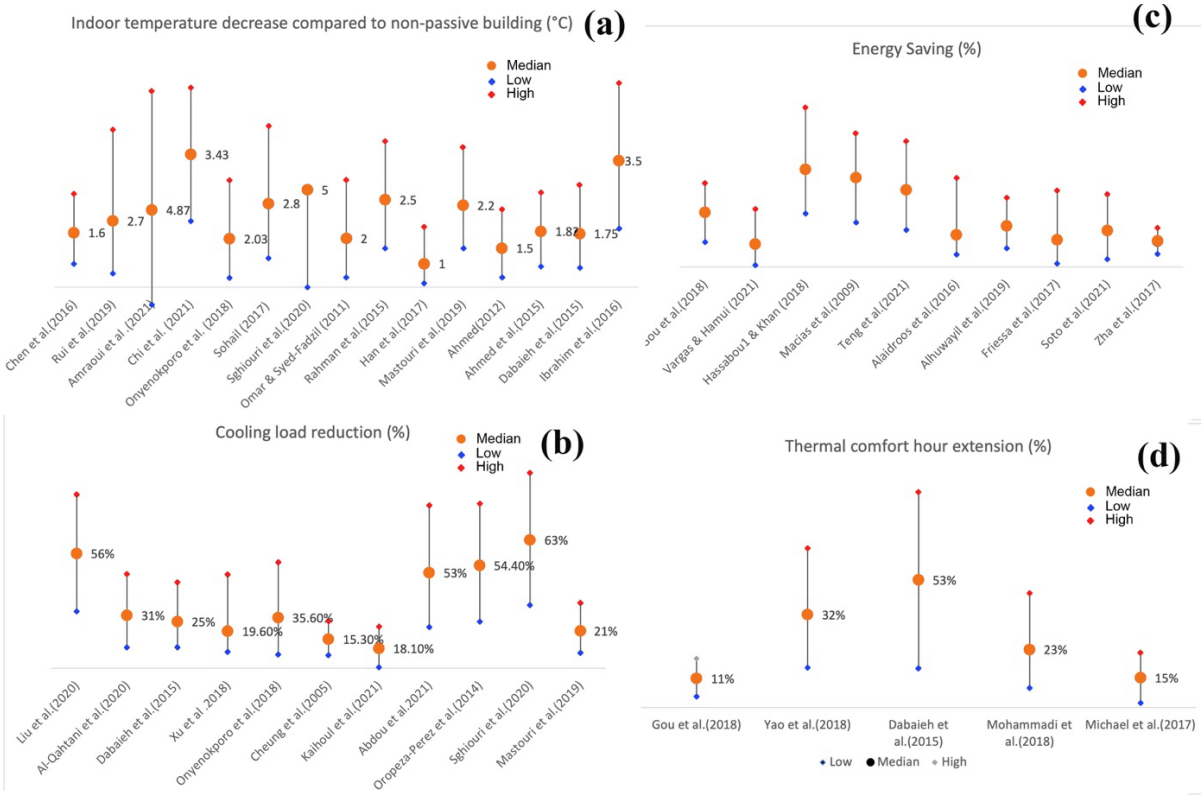


Figure 3: Effective measurements of passive cooling strategies: (a) cooling load reduction, (b) energy savings, (c) indoor temperature decrease compared to non-passive buildings, and (d) thermal comfort hour extension. Source: (Author 2023)

The third measurement is energy savings (refer to Figure 3c), with the median savings ranging between 14.5% and 49.5%. The highest reduction reported was 70% from studies on mid-rise apartment buildings in Qatar (Khan et al. 2018). The researchers simulated the combined effects of PSC9, PSC10, PSC12, and PSC19. The lowest energy saving (2%) was reported by Vargas & Hamui (2021) who used a simulation of a single-family attached house in Mexico. To reduce the solar gain, the researchers proposed adding additional glass, with a thickness of 13 mm, to all existing single-pane windows and changing all aluminum frames to wooden frames. Further, the research team found that adding more insulation on the roof could result in a substantial increase in energy savings, at 13.7% (Vargas and Hamui 2021).

The fourth measurement is the comfort hour extension, the least used metric. As listed in Figure 3d, only five studies used this measure. The median thermal comfort hour extension ranges between 10.8% and 53%. The highest effect (53% extension) was found in mid-rise apartment buildings in Cairo, Egypt, using a combination of PCS4 and PCS20, a vault roof with a rim angle of 70 and high-albedo coatings (cool roof). The comfort hours can be extended from 816 hours to 1,735 hours, which is a significant increase in hot and dry climates (Dabaieh et al. 2015).

Two overall conclusions can be drawn. First, there are consistent, significant benefits of the individual and combined passive strategies in all four measurements in all climate conditions across countries. The empirical evidence, as demonstrated in Figure 4, concludes that a combination of low-cost passive strategies can lead to an average energy savings of 31%, a cooling load reduction of 29%, a thermal comfort hour extension of 23%, and an indoor temperature decrease of 2.20°c. Second, studies on passive techniques in vernacular buildings using actual measurements show promising results of indoor temperature reductions in Algeria, China, and Malaysia and of a cooling load reduction in China, Iran, Cyprus, and Algeria Xu et al. 2018; Kaihoul et al. 2021; Mohammadi et al. 2018; Yao et al. 2018; Michael et al. 2017). These findings demonstrate that localized low-cost design solutions are readily available, and learnings from traditional and vernacular buildings should be prioritized, especially in developing countries.

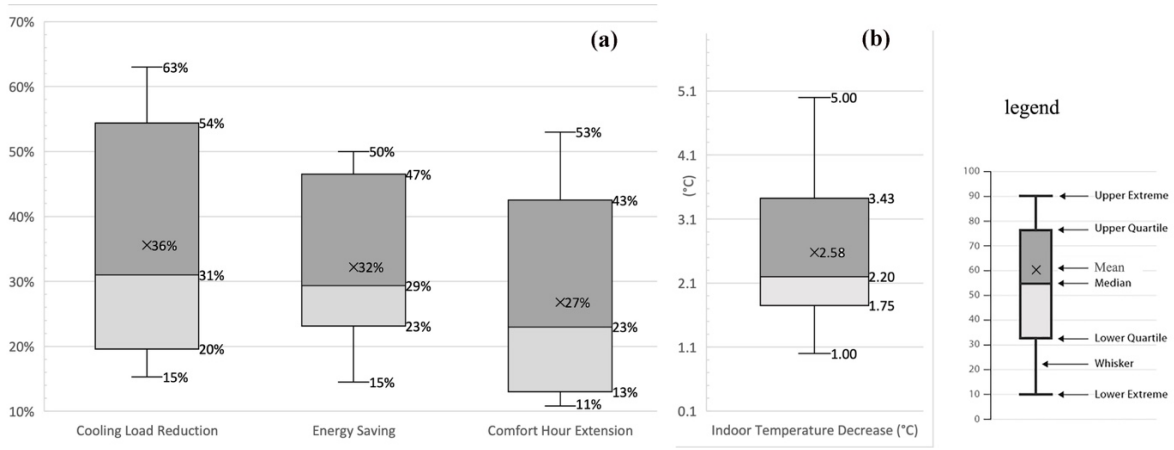


Figure 4: Effectiveness of combined passive strategies (a) cooling load reduction, energy saving, thermal comfort hour extension. (b) indoor temperature decrease. Source: (Author 2023)

CONCLUSION

Climate change will continue to impact the built environment as global warming exacerbates extreme heat events. As a result, many residential buildings are at risk of overheating. Meanwhile, overreliance on mechanical cooling can lead to higher energy consumption. Most research and practice foci have concentrated on active (mechanical) cooling technologies since potential cooling demand reductions through the adoption of passive design have not been fully understood. To the author's knowledge, this is the first systematic review and meta-analysis conducted on empirical evidence of the effectiveness of PCSs. This review includes empirical studies from 2000 to 2021, with 30 passive strategies found and related effectiveness measurements extracted. The meta-analysis provides solid evidence illustrating the benefits of low-cost passive strategies in the categories of cooling load reduction, indoor temperature decrease, thermal comfort house extension, and energy savings. Several passive strategies have been identified as primary factors to be studied and implemented. Based on the review findings, Figure 5 represents a proposed conceptual framework of major housing PCSs that have mitigation and adaptation effects regarding climate change. Six PCSs were identified as most effective, including PCS10, PCS12, and PCS23, and are applicable in all hot climates. PCS17 is appropriate for hot and humid climates, while PCS9 is suitable for hot and dry climates.

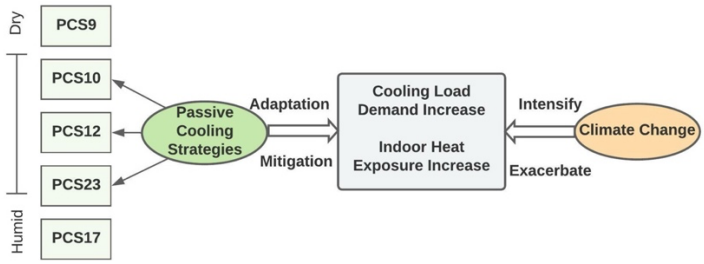


Figure 5: Conceptual framework for adaptation and mitigation. Source: (Author 2023)

More PCSs can be added for specific locations depending on further studies. This framework can be used to inform future design guidelines, regulations, or policies for new buildings to mitigate future extreme heat events, or for retrofitting existing housing to become more adaptive to the changing climate. The identified climate adaptive PCSs are straightforward and low cost. Their success is also dependent on specific knowledge of the site conditions and certain implementation methods that are unique to individual buildings. This framework merely serves as the first step in identifying and defining the effective PCSs. Conducting further assessments to identify the optimal quantities for specific sites is the next task for individual project teams, local building regulatory agencies, and involved stakeholders.

ACKNOWLEDGEMENTS

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Multi-Robotic 3D Printing Wood-Based Slurry on Construction Scale

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ABSTRACT: In response to the escalating demand for rapid urbanization, the construction industry is compelled to shift towards sustainable alternatives, aiming to overcome various challenges, including shortages in skilled labor, material scarcity, and environmental degradation stemming from conventional and inefficient construction methods. 3D Printing (3DP) offers a transformative solution by digitizing construction processes and enabling the investigation of novel, sustainable materials that are biodegradable, reusable, and recyclable. Among these materials are wood-based slurry materials, which have the potential to divert 3 million tons of wood waste directed annually to landfills in the United States and recycle it in the production of various construction elements, making a step towards circular construction practices. This research investigates MR-3DP using wood-based slurry to manufacture ultra-lightweight, large-scale building components. This paper presents research that aims to investigate and understand the process parameters associated with the success and failure of printing construction scale objects using Multi-Robotic 3D Printing (MR-3DP) with wood-based slurry material. This is investigated through the design and fabrication of two non-load-bearing cavity wall prototypes.

KEYWORDS: Multi-Robotic 3D Printing, Wood-based material, Sustainable construction practices, Circular economy in construction, Large-scale additive manufacturing

INTRODUCTION

The construction industry has to respond to the rising need for rapid urbanization (Cohen 2006), yet it is hindered by challenges, including low productivity, a shortage of skilled labor, construction materials scarcity, and the negative environmental impacts resulting from inefficient traditional construction methods (Crawford and Vogl 2006; Klemmt et al. 2022). Given these issues, there is a pressing need for alternative sustainable construction methods. 3D Printing (3DP) emerges as a promising solution capable of addressing these challenges by digitizing the construction industry and fostering the development of novel material explorations that are fully biodegradable, reusable, and recyclable, thus paving the way for more sustainable construction practices. 3DP only deposits material where needed, facilitating the creation of optimized, lightweight structures that significantly reduce waste compared to conventional construction methods. Particularly, Robotic 3D Printing (R-3DP) enhances the capabilities of 3DP, enabling the fabrication of more complex structural elements with extraordinary multifunction on a large scale (Kamhawi et al., 2024a, Kamhawi et al., 2024b, Aghaei Meibodi et al., 2024).

In recent years, 3DP with wood-based slurry has captivated significant attention and was investigated in multiple research, as it offers the potential for recycling 3 million tons of sawdust produced annually in the United States (Batool et al. 2021), paving the way for circular construction practices. The presented paper expands upon the existing body of research by exploring the potential applications of multi-robotic 3DP (MR-3DP) with wood-based slurry for the construction of large-scale building elements. By leveraging the opportunities of multiple robots working together, MR-3DP can significantly accelerate the construction process, allowing for the fabrication of complex, large-scale structures, which not only enhances productivity but also enables the realization of intricate architectural features that were previously difficult or impossible to achieve with a gantry-based 3D printer or single robot 3D printing system. While the application of multi-robotic strategies has been extensively investigated within the context of assembly tasks in research groups such as Gramazio Kohler Research, Block Research Group, and Digital Building Technologies at ETH Zurich or ICD at the University of Stuttgart (Thoma et al. 2019; Leder et al. 2019; Wang et al. 2023; Wagner et al. 2020), very limited research has been conducted on MR-3DP. Stands out as one of the few, if not the only, research efforts in this area is the work at Nanyang Technological University (Zhang et al. 2018) on developing a MR-3DP system that utilizes a team of mobile robots to cooperatively print a single concrete structure aiming to address the challenge of scalability associated with 3DP in construction scale.

1.0 RESEARCH METHOD: MULTI-ROBOTIC 3D PRINTING WITH WOOD-BASED SLURRY

This research investigates the use of MR-3DP with wood-based slurry to produce ultra-lightweight building components on a large scale. The study is conducted through the design and fabrication of a construction-scale prototype of two non-load-bearing cavity walls (Figure 1). The first prototype is manufactured using a R-3DP, and the second utilizes a MR-3DP fabrication system. The prototype has a square base plan that measures 1.3m x 1.3m and depicts the design of a double wall conventionally used in 3D concrete printed houses. The cavity in the double wall hosts a series of ribs that provide structural stability for the element, while the voids in between the ribs

can host thermal insulation. The presented paper aims to experimentally understand the various parameters contributing to the success and failure of the fabrication of the designed prototype. This paper presents preliminary research into the application of MR-3DP with wood-based slurry at a construction scale. It identifies the challenges and opportunities associated with this method and presents tentative preliminary data that helps focus and refine future research questions in this field. MR-3DP with wood-based slurry entails the development of several interconnected areas:

1. **Material Design:** Exploring and refining the formulation of wood-based slurry materials for 3D printing purposes, particularly focusing on developing and recycling wood-based slurry materials. The paper highlights the importance of finding the right material ratios for successful pumpability, extrudability, and buildability. Additionally, the material buildability is evaluated using single-robot printing to understand how changes in material viscosity related to various material designs impact the 3DP process.
2. **MR-3DP Process Parameters Control and Fine-Tuning:** Understanding and fine-tuning process parameters within MR-3DP when working with wood-based slurry that influences precise material deposition, buildability, and geometric fidelity. The goal is to understand and identify various process-related parameters, such as material pumping rate, nozzle printing speed, and nozzle diameter, alongside the coordination of multiple robots that impact consistent and reliable material deposition. The aim is to derive relationships to enable future fine-tuning of parameters.
3. **Task Division, Path Planning, and Motion Planning:** The objective is aimed at maximizing the efficiency and effectiveness of the collaborative printing process, ensuring that each robot's path is optimized to minimize overlap and interference while also enhancing the overall speed and quality of the 3DP process.

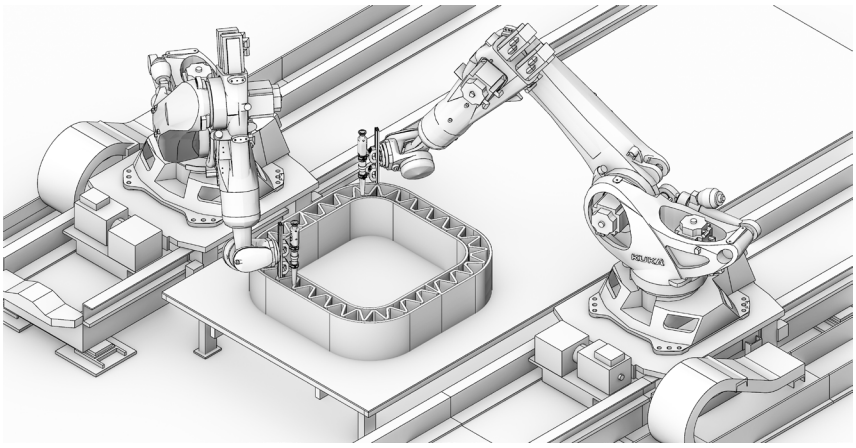


Figure 1: The developed construction scale prototype. Source: (Created by the authors 2024)

2.0 WOOD-BASED SLURRY MATERIAL DESIGN AND BEHAVIOUR IN RELATION TO THE 3DP PROCESS

2.1. State of the art in wood printing

In the pursuit of eco-friendly and sustainable practices within the construction industry, this research has extensively investigated material compositions for 3DP. The environmental footprint of wood-based materials, especially in the context of additive manufacturing, is aimed to be enhanced. The ingredients chosen for the formulations are entirely organic and renewable, ensuring recyclability without compromising the material's inherent characteristics. This approach aligns with the research's commitment to promoting sustainable, environmentally friendly construction practices and contributing to a circular economy.

Two additive manufacturing techniques have been commonly used to investigate 3DP with wood: Hot extrusion, which entails heating the material before extruding it from the printing toolhead, and cold extrusion, which involves pushing the material out of the toolhead at ambient temperature. In contrast to hot extrusion techniques, which demand high temperatures, cold extrusion enables the shaping and molding of construction materials at room temperature or slightly elevated temperatures (Materiability Research Group 2020). The hot extrusion method involves using a filament feedstock composed of 70% plastic and only 10 to 30% wood. The elevated temperature during hot extrusion also presents a potential hazard of burning the wood filaments in the process (Krapež Tomec and Karič 2022; Das et al. 2021). The cold extrusion approach offers several advantages for the construction sector, including the ability to work with heat-sensitive materials like wood and a reduction in energy consumption. However, achieving precise dimensional accuracy to align with the digital twin model presents a challenging task. Consequently, this research builds on previous research presented by DART Laboratory (Muhammad Dayyem Khan et al. 2023) and will concentrate on cold extrusion for a newly developed wood-based material for 3D printing.

Most research in 3DP wood focuses on developing wood-based slurry to overcome challenges related to scalability, deformation, and mechanical strength. Most material compositions investigated in 3DP with bio-based material still constitute a modest proportion of wood-based content and are often supplemented by synthetic resins or thermoplastics like High-Density Polyethylene (HDPE).

(Wei et al. 2022) in their work successfully presented a bio-material that did not include any wood-based content by combining chitosan and cellulose with essential ingredients: xanthan gum to improve viscosity, dimensional stability, printability, and uniformity and flour and paper fiber to reduce shrinkage and enhance mechanical strength. Other researchers (Bierach et al. 2023) were successful in developing a new material derived from both biobased and wood sources. However, it was observed that the mechanical properties of the material underperform in comparison to those of wood, carbon fiber-reinforced polymers, and thermoplastic. 'BioHome3D' is a research project presented by researchers from the University of Maine (Ward Taylor 2022); the research presented a 600-square-foot prototype house built with wood fiber and bio-resin-based material using FFF 3DP. For optimized printability, researchers use a blend of high-grade biopolymers and pine fibers. Including wood fibers improves the rheology's cooling properties, reducing both setting time and challenges related to deformation. Using non-biodegradable bio-resins or thermoplastics in 3D printing wood-based slurry materials poses challenges in recycling and lacks eco-friendliness compared to biodegradable alternatives. This obstacle impedes the advancement of environmentally friendly construction practices. Despite wood's traditional role in building construction, there has been little research in exploring 3D-printed wood-based materials for construction. This study is committed to developing a scalable, easily recyclable, biodegradable wood-based slurry material specifically designed for MR-3DP.

2.2. Wood-based slurry processing and recycling

A comprehensive approach was taken to achieve a material design for a 3D-printable wood-based slurry, prioritizing printability, 100% recyclability, and biodegradability. The wood-based material consists of a blend of bio-polymers, additives, and solvents. Bio-polymers, sourced from natural origins like chitosan, flour, and xanthan gum, act as renewable binders. Additives, including sawdust, cellulose, paper pulp, magnesium oxide, calcium chloride, and calcium carbonate, enhance strength and regulate moisture. Solvents such as water and acetic acid optimize viscosity, creating a sustainable and versatile material for 3D printing.

To attain optimal viscosity, a set of 20 tests was carried out using a manual syringe extrusion technique, emphasizing considerations of stability and extrudability. Systematic experimentation encompassed a range of material compositions, with a specific focus on elevating concentrations of strengthening additives to induce an increase in viscosity, thereby aiming to achieve favorable material extrudability and buildability. Following a comprehensive assessment, a conclusive composition featuring 42.5% sawdust and 13.9% paper pulp was identified as optimal, satisfying criteria related to buildability, printability, and extrudability. Additionally, the ongoing monitoring of setting time remains imperative to facilitate expedited solidification processes. (Figure 2) showcases the most significant viscosity tests, highlighting the ease with which they were extruded, as well as curing time and measured shrinkage after curing. The material mix for these tests and the final material mixes are included in (Table 1).



Figure 2: Different material compositions employed in experiments for material research. Source: (Created by the authors.)

Table 1: Different material compositions employed in experiments for material research. Source: (Created by the authors 2024)

	Xanthan Gum	Wood Dust	Cellulose	All Purpose Flour	Paper Fiber	Chitosan	Calcium Carbonate	Magnesium Oxide	Acetic Acid	Calcium Chloride	Water
T6	2g	8g	16g	2g	8g	2g	1.5g	N/A	4g	1.5g	70g
T7	2g	N/A	8g	2g	8g	2g	4g	5g	4g	1.5g	80g
T8	2g	8g	16g	2g	8g	2g	N/A	10g	4g	1.5g	80g
T12	4g	16g	8g	4g	12g	2g	4g	15g	4g	1.5g	90g
T15	4g	8g	16g	4g	8g	2g	4g	10g	4g	1.5g	120g
T16	4g	8g	N/A	4g	16g	2g	4g	10g	4g	1.5g	110g
F1	**152g**	**610g**	**304g**	**152g**	**457g**	**75g**	**100g**	**578g**	**152g**	**61g**	**4500g**
F2	**152g**	**610g**	**304g**	**152g**	**457g**	**75g**	**100g**	**578g**	**152g**	**61g**	**5750g**

This research delineates a four-stage method for preparing wood-based material for R-3DP. In the initial stage, sawdust is ground to achieve a millimeter to sub-millimeter particle size, ensuring dimensional stability. The second stage involves mixing 42.5% sawdust and 13.9% paper pulp with water to attain a mache consistency. Subsequently, cellulose (9.3%), calcium carbonate (4.7%), and magnesium oxide (11.6%) are added to provide strength and mold resistance. Binding agents, including flour (4.7%), xanthan gum (4.7%), and chitosan (4.7%), contribute to viscosity and adhesion. Activation with solvents like water and acetic acid results in a slurry. The addition of calcium chloride acts as an accelerating agent and reduces settling time. A commercial mixer is

employed to create a cohesive material suitable for 3D printing (Figure 3). After material preparation, a slump test ensures a slurry-based paste for continuous extrusion by the robot systems' pumps.



Figure 3: Material mixing process. Left to right: Paper pulp, saw-dust, hydrated mix of paper and saw-dust, dry mix of other ingredients, and final slurry. Source: (Created by the authors.)

The recycling process is closely linked to the moisture content retained by the material. When the material holds 50%-60% moisture, it is introduced into the mixer and hydrated to reach the required consistency. Throughout this hydration phase, ingredients such as flour, chitosan, and xanthan gum are reactivated, thereby preserving the material's structural and chemical integrity. Conversely, if the material is completely dry, it is first pulverized to a submillimetre granularity before being added to the mixer. Water is then incrementally introduced until the target consistency is obtained. Once the desired texture is achieved, the material becomes suitable for the printing process. Remarkably, this material can undergo multiple recycling rounds without a decline in its inherent properties and quality (Figure 4).



Figure 4: Material recycling process from bone dry to slurry. Source: (Created by the authors 2024)

3.0 MULTI-ROBOTIC WOOD 3D PRINTING FOR CONSTRUCTION

3.1. Multi-robotic 3D printing fabrication system architecture

The multi-robotic 3D Printing fabrication system in this research entails material pumps, 3D printing end effectors, and robotic arms. The setup for MR-3DP with wood-based slurry in this study involves:

1. **Two industrial robotic arms** KUKA KR-120s were specifically chosen for their robust payload capacity. This ensures they can comfortably handle the weight of the 3D printing nozzles and the hose filled with material. At the same time, their extensive motion range enables complete coverage of the printing area measuring 1.3m x 1.3m.
2. **Two cold extrusion 3D printing end effectors** with a nozzle of a diameter of 2.5 cm.
3. **Two pumps with digital variable rates** the MAI 2PUMP-PICTOR and a custom in-house designed pump. The latter is powered by a Beckhoff servo motor, providing a continuous torque output of 2.7 Nm with an operational speed range of 0 to 1000 rpm. To ensure a uniform and synchronized material flow using these two distinct pumps, the pumping parameters were fine-tuned according to their respective volume capacities.
4. **A robotic control system** designed to ensure seamless synchronization between the two robotic 3DP processes—pump flow rates and the robot's motions, which include the speed of material deposition along the print path. This coordination is achieved through Beckhoff PLC, with distinct logical I/O control for each pump aligned with its respective robot and 3D printing end-effectors.
5. The MR-3DP system's infrastructure is further supported by two 5m hoses, each connected to the cold extrusion 3DP end effectors. The operation is overseen by three human operators. Two were responsible for initiating the print programs and continuously monitoring the process to ensure continuous material flow, precise material deposition, and structural integrity of the part being 3D printed (Figure 5). The third person was responsible for supplying the feedstock material, ensuring an adequate supply to the pumps, and manually assisting in pushing the material from the hopper to the pump. While pumping the highly viscous wood-based slurry, the viscosity itself remained consistent with our pump. The major challenge

arose in manually pushing the material into the pump, as there was no automated system for this phase, requiring manual intervention.

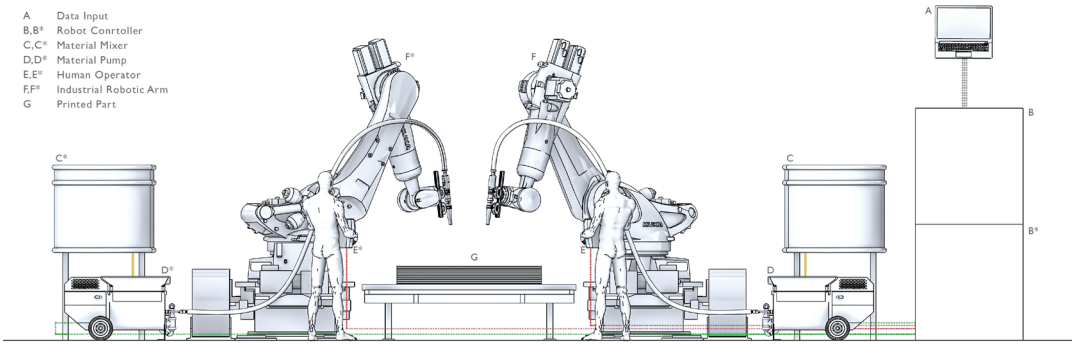


Figure 5: Multi-Robotic 3D Printing for Wood-Based Slurry Fabrication System Architecture. Source: (Created by the authors 2024)

3.2. Print path slicing and motion planning

The control of both robotic 3DP systems is achieved by loading and running two KUKA SRC files on two separate robot controllers. SRC files are source code files used by KUKA robotic arms; the SRC file contains plain text written in KUKA Robot Language (KRL). KRL is used for defining robot movements, handling inputs and outputs, data manipulation, and integration with external devices. A multi-step software workflow was developed to generate the two SRC files to optimize the processes-related parameters in the two-robotic 3D Printing with wood slurry (Figure 6):

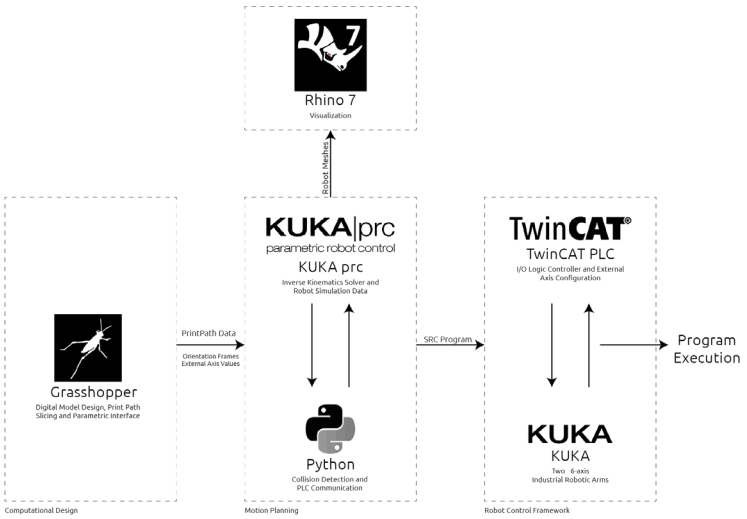


Figure 6: Software Workflow Demonstrating the Digital Design to Fabrication Process. Source: (Created by the authors 2024)

1. Grasshopper plugin to Rhinoceros modelling software was utilized to develop the computational design model of the prototype, slicing the resulting geometry into print path and generating the orientation frames for each robot based on their respective print path. The orientation frames are pivotal in determining how the robots would navigate and coordinate their actions within the shared work cell. This aspect of the workflow was strategically designed to maximize the efficiency and effectiveness of the collaborative 3D printing process. The print paths and orientation frames were optimized to minimize possible overlap between both robots while performing the 3DP, ensuring a harmonious operation where the robots can work side by side without disrupting each other's tasks (Figure 7).
2. The orientation frames are used as input for KUKA PRC to solve the inverse kinematics of the robots. This step results in the determination of the final joint positions for each robot, ensuring they move accurately and efficiently in the designated printing area.
3. The robot joint positions are used as input for a custom Python script developed to detect collisions between all states of the MR-3DP system. To minimize computational time, the Python script starts by wrapping a simple convex hull around each robot, followed by the application of the GJK (Gilbert-Johnson-Keerthi) algorithm (Lindemann 2009), an algorithm that runs an iterative search for the smallest distance between two convex sets and is capable of determining if an overlap has occurred between them (Figure 7).
4. Rhinoceros 3D acts as the visualization platform for the collision detection simulation, offering a detailed view of the two robotic 3d printing process along the generated print path, and allowing for adjustments of print path in areas of collision before final execution.
5. Finally, the resulting configurations are compiled in an SRC program file. This file not only includes the detailed joint states of each robot but also integrates the operation of external axes, like those controlling

the material pumps, ensuring seamless synchronization between the movement of the robots and the delivery of the wood-based slurry.

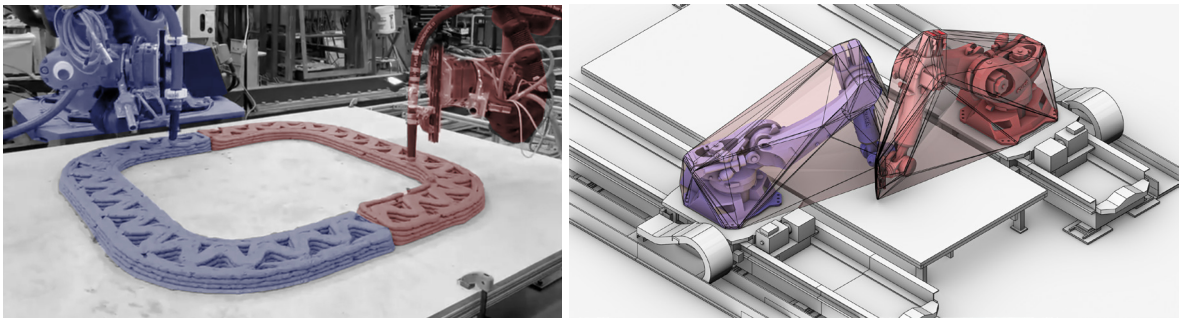


Figure 7: Left image: Task division and coordination in the multi-robotic 3D printing process, Right image: Collision detection using a simple convex hull and Gilbert-Johnson-Keerthi algorithm for faster collision computation. Source: (Created by the authors 2024)

This integrated software and hardware approach facilitates a highly coordinated and efficient MR-3DP process, which was employed in the fabrication of a construction scale wall (Figure 8). The printing process for the wall case study was planned to synchronize the nozzle printing speed and pumping flow rates, ensuring a consistent flow of material from the pump to the end effector in a way that matches the movement speed of the robots. To achieve a layer height of 13 mm, the pumping rate was set at 0.25 liters per minute, a robot speed of 0.015m/s. For this prototype, the lower viscosity material composition (F2) was used. This material was modified based on the final material design (F1) achieved by (Muhammad Dayyem Khan et al. 2023). This modification was a result of the pumping limitations of the MAI 2PUMP-PICTOR, which is not capable of handling the high viscosity of material (F1).

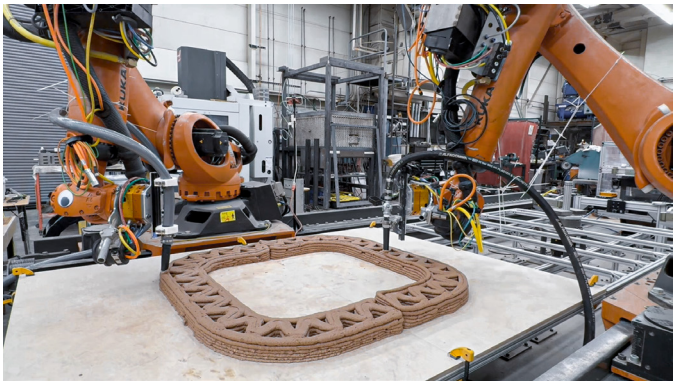


Figure 8: Resulting construction scale prototype from the MR-3DP process with wood-based slurry material using material (F2). Source: (Created by the authors 2024)

4.0 WOOD 3D PRINTING OF SLURRY WITH A SINGLE ROBOT

The aim of this prototype is to measure the effect of the material viscosity and layer cycle time on the buildability of the printed object; thus, the more viscous material (F1) was used in this case study in addition to printing with a single robotic arm. As described in the previous section, the MAI 2PUMP-PICTOR pump posed a limitation on the viscosity of the material that can be printed. In contrast, the custom in-house designed pump, therefore it was utilized in this experiment, can handle more viscous materials. To get an accurate evaluation, all the printing parameters for the MR-3DP experiment were replicated in this experiment. Consequently, the pumping rate was set at 0.25 liters per minute. The robot speed was set at 0.015m/s to achieve a layer height of 13 mm. (Figure 9) showcases the resulting prototype from the experiment. The experiment was conducted over two days, 9 layers were printed over the course of the first day, followed by the printing of 8 layers on the second day.

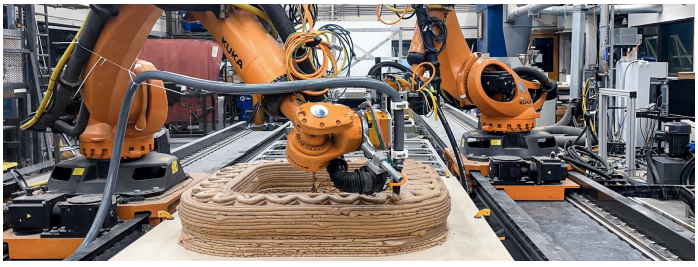


Figure 9: Resulting construction scale prototype from the R-3DP process with wood-based slurry material using material (F1). Source: (Created by the authors 2024)

5.0 RESULTS AND DISCUSSION

1. The developed MR-3DP system enabled the production of a prototype that is 78 mm high and 1.3 m x 1.3 m in length and width. The 3DP process took 45 mins, and each print layer took between 7-8 mins. In comparison, the prototype resulting from the R-3DP process has the same footprint but achieved a height of 221 mm. The 3DP process took 289 mins, and each print layer took between 15-18 mins. Both cases required similar material preparation time of about 5-6 hrs.
2. The 3DP experiment conducted with a single robotic arm was able to successfully print 17 layers, while the one with the MR-3DP system only achieved 6 layers before layer deformation occurred. This disparity in the construct's performance can be traced back to the difference in the layer cycle time, where the R-3DP scenario is approximately double that of the MR-3DP, which allows the material more time to set before the deposition of fresh material.
3. The 3D printed construct produced by both setups ultimately experienced a plastic failure. The lower layers failed to support the weight of the newly deposited material above, leading to the structure's collapse (Figure 10).
4. Rheological properties significantly impact the performance of 3D-printed constructs. Previous prototypes using low-viscosity wood-based slurry faced severe delamination due to high water content causing uneven shrinkage across layers (Figure 10). This issue highlights the need for further research into the slurry's rheological characteristics. Uneven water loss during various stages of MR-3D printing, especially during pumping, contributes to this problem. The goal is to keep the slurry fluid during pumping while ensuring it retains its form upon extrusion. Future advancements should focus on developing inorganic accelerators for wood-based slurry and integrating these accelerators at the end effector to control setting time, optimizing the process for better structural integrity and precision.

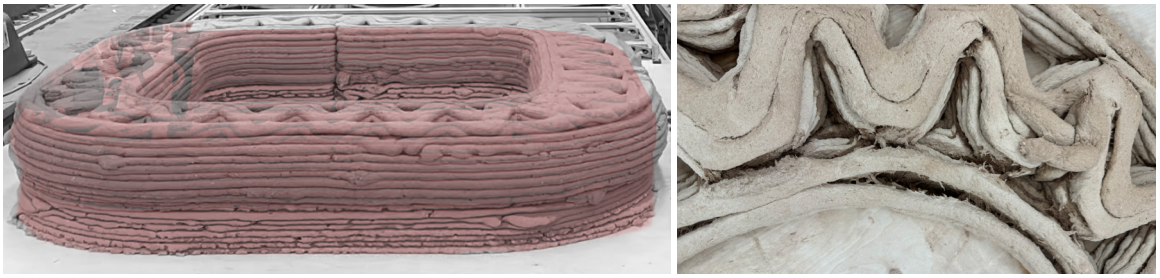


Figure 10: Left image: Deformation resulting from the plastic failure in the prototype printed through the R-3DP, Right image: Demonstrates the delamination of the object manufactured using the MR-3DP process using material (F2). Source: (Created by the authors 2024)

5. The division of 3D printing tasks was strategically managed by bisecting the object down the center to create two distinct print paths for each robotic arm. This minimized the possible areas of overlap, thus reducing the chances of collision between the two robotic arms. This approach also resulted in two continuous seams throughout the object, which can result in reduced mechanical and structural performance. To address this, future research should explore alternative seam positioning across multiple layers to eliminate division across the object and evaluate its impact on overall performance. This investigation may encompass an analysis of how seam placement influences structural strength, durability, and aesthetic attributes.
6. The need for a third operator to supply material stock and continuously agitate the material to ensure continuous feeding to the pump represents a major bottleneck in the automation and scalability of the whole process; not only that, but it also introduces the potential for inconsistent material extrusion, Addressing this by integrating a fully automated feedstock supply system could significantly enhance the overall efficiency and reliability of the MR-3DP process.
7. While the 3DP process was monitored by two operators in MR-3DP, there were multiple challenges that arouse while attempting to real-time modify and synchronize the robot 3DP settings, such as robot motion speed and material flow rate, between both robots. This highlighted a need for a more intelligent robot control system that would facilitate an enhanced level of collaboration between both robotic printing setups.

CONCLUSION

The presented research showcased the opportunities and challenges of MR-3DP with wood-based slurry for construction applications. This was achieved through a comparative analysis between two prototypical construction walls; the first was manufactured using R-3DP and the second MR-3DP. Significant insights into the various process parameters and material-related parameters were gained from these comparisons such as the effect of layer cycle time and material viscosity on the structural integrity and buildability of printed objects. Additionally, these experiments revealed the need for further research into the thixotropic properties of wood-based slurry and the benefits of developing a set on-demand process for this material.

Key process-related parameters critical for successful buildability were identified, which include, Material mixing time, the time interval between material mix and feeding the material into the material pump, material feeding rate, material flow rate through the pump, material travel time from pump to 3D printing nozzle, 3D printing nozzle

diameter relative to the material carrying hose diameter, ambient temperature, layer cycle time relative to the material setting time, robot motion speed as well as the synchronization between both robots. This paper laid the groundwork for future research by understanding the various effects and relations some of these parameters have on the MR-3DP process. Further data collection needs to be conducted in order to accurately identify the correlation between these parameters in order to optimize them for a more streamlined and efficient MR-3DP.

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Considering Complexity + Navigating Change: An Integrative Strategy for Addressing Contemporary Challenges in Architectural Design

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ABSTRACT: Our rapidly evolving world, where change is commonplace and often daunting, presents pressing challenges, including resource depletion, environmental degradation, and socio-cultural complexities. Amidst these forces, architectural design urgently demands creative and sustainable solutions (Pour and Sinclair 2015). Design potency, relevance, and fit require critical reassessment, recognizing the built environment's profound impact on quality of life. While essential across building typologies, these needs are most pronounced in housing design. The cultural pluralism and ethnic diversity of a country such as Canada shapes diverse lifestyles, and therefore necessitates dwellings that are mixed-income, mixed-purpose, agile, adaptable, and sustainable (Kendall 1999).

This paper presents research deploying unconventional design approaches, including the crafting of a novel five-step methodology juxtaposing agility and innovation. This research critically examines notable conceptual frameworks: notably Gordon's 3Ls, Elkington's Triple Bottom Line, Sinclair's Holistic Framework for Design + Planning, and Imam's Agile Architectural Framework. Ultimately, such models are assessed against prominent architectural landmarks –the new Calgary Central Library (Architects: Snohetta + DIALOG), MacKimmie Tower (Architects: Ron Thom, renovated by DIALOG), and Habitat 67 (Architect: Moshe Safdie). Through comparative analysis, this study identifies deficiencies within aforesaid frameworks, synthesizing findings to develop a hybrid, more efficacious and durable model —the *Transformation Framework*. This approach necessitates a thorough understanding of these conceptual frameworks and their applicability in the evolving context of architectural design. Rethinking design at a base level broadens its relevance across typologies, with housing as a primary focus yet extending beyond. As part of a larger research agenda, this paper highlights core concepts and proffers strategies underpinning this novel hybrid approach.

It is important to stress that identified frameworks, understandably shaped by the condition and constraints of their respective periods, necessitate reconsideration. Accordingly, this study rethinks more timeless attributes—longevity, adaptability, and diversity —to better address contemporary and emerging demands. Shifting from isolated evaluations, it advances a broader, integrative perspective to pave the way for the convergence of a more diverse architectural set of principles (Bahonar and Sinclair 2023). The Transformation Framework offers a novel paradigm with the potential to empower users, promote sustainable practices, and encourage responsive environmental design. This research highlights an innovative and timely step toward holistic, enduring approaches to design. The model has meaningful applicability to housing and other typologies -- drawing from the past, embracing the present, and anticipating the future.

KEYWORDS: design, framework, agility, sustainability, holism

INTRODUCTION

As the third decade of the 21st century unfolds, the architectural landscape is marked by a period of profound changes. The global pandemic, socioeconomic shifts, and heightened environmental awareness have prompted a revaluation of architectural paradigms once adequate for simpler times (Bahonar and Sinclair 2023). Today's architecture is not merely about erecting structures; it demands resilience, adaptability, and an acute response to dynamic challenges like public health crises, climate change, and evolving societal norms (Rogers 1998; Sinclair 2023).

This context sets the stage for a critical examination of existing architectural frameworks. Traditional models, while foundational, may lack the comprehensive adaptability required in the rapidly changing architectural environment. This paper builds upon the groundwork laid in previous research, critiquing and expanding upon established frameworks like Gordon's 3Ls, Elkington's Triple Bottom Line, Sinclair's Holistic Framework for Design + Planning, and Imam's Agile Architectural Framework. The research uniquely juxtaposes these four models against three case studies: the new Calgary Central Library (Architects: Snohetta + DIALOG), MacKimmie Tower (Architects: Ron Thom, renovated by DIALOG), and Habitat 67(Architect: Moshe Safdie), as paradigms of modern architectural excellence, to uncover potential gaps and synthesize a more effective model (Figure 1). In response to these insights, this study introduces *a Transformation Framework*, a novel conceptual model tailored to contemporary architectural needs. The Transformation Framework represents an evolution in design thinking, intertwining agility,

sustainability, and user-centric considerations to form a responsive and holistic approach to architectural challenges. By bridging theoretical underpinnings with practical applications, this paper aims to contribute a meaningful addition to architectural design discourse while maintaining relevance across various building typologies.



Figure 1: Selected contemporary architectural case studies. From left to the right: the new Calgary Central Library (Architects: Snohetta + DIALOG, Location: Calgary, Alberta, Canada), The MacKimmie Tower (Architects: Ron Thom, renovated by DIALOG, Location: Calgary, Alberta, Canada), and Habitat 67(architect: Moshe Safdie, Location: Montreal, Quebec, Canada). Source (From left to right): (Sinclair 2023) (Bahonar 2024) (Gabrieled 2013)

1.0 BACKGROUND – EXPLORING THE EXISTING FRAMEWORKS

In this architectural discourse, four principal frameworks have emerged, each marking a significant evolution in the field. Sir Alex Gordon's 3L's Framework, introduced in the early 1970s, presents a pioneering approach with its emphasis on "loose fit, long life, and low energy". This framework reflects a deep understanding of sustainability, advocating for designs that are durable, adaptable, and resource-efficient – a reflection of the environmental consciousness growing in architecture at the time (Imam 2022). In the mid-1990s, John Elkington introduced the Triple Bottom Line (TBL) framework, expanding the perspective of architectural sustainability to encompass economic, social, and environmental dimensions. TBL's holistic approach evaluates the financial viability, community impact, and ecological considerations of architectural projects. This framework resonates with a growing awareness of the interconnectedness of financial responsibility, social equity, and environmental stewardship in architectural practices (Elkington 2013). Established in 2009, Sinclair's Holistic Framework for Design + Planning, offers a comprehensive methodology addressing urban and architectural design challenges. It highlights four key action areas: Agility, Fitness, Diversity, and Delight. Agility emphasizes responsive and adaptable design, while Fitness addresses the appropriateness of the design in relation to community needs. Diversity advocates for varied land uses and inclusivity, and Delight focuses on the aesthetic and emotional impact of architectural spaces. Sinclair's framework seeks to reconcile fragmented aspects of urban design, advocating for a responsive and integrated approach to environmental design (Sinclair 2009). As the most recently established framework among the four, Salah Imam's Agile Architectural Framework emphasizes the integration of agility in architectural design. This framework is geared towards creating buildings that are adaptable, flexible, and sustainable, focusing on enduring and responsive design. It incorporates a multi-criteria decision-making process, addressing physical, functional, economic, technological, social, legal, and political aspects of building projects. Imam's approach is characterized by its holistic perspective, blending open building concepts, holistic design, and systems thinking to craft buildings capable of evolving with their environment. This agility-oriented framework is particularly relevant in the face of the dynamic and uncertain nature of modern architectural demands (Imam and Sinclair 2022).

It is important to mention that these frameworks, each a product of its time, share a common objective: namely, to address the evolving demands of architecture. They reflect an adaptive discipline, responsive to the challenges and opportunities presented by their respective eras. The study of these frameworks offers insights into the progression of architectural thought, highlighting the shift from examining frameworks in isolation to a more interconnected and diverse approach. This evolution signifies a move towards a more nuanced understanding of architecture, one that recognizes the complex interplay between environmental, social, and economic factors (Bahonar and Sinclair 2023; Sinclair 2023).

2.0 METHODOLOGY

The methodology of this paper revolves around a nuanced exploration and application of architectural frameworks in real-world contexts. It begins with an in-depth theoretical analysis of established frameworks such as Gordon's 3Ls, Elkington's Triple Bottom Line, Sinclair's Holistic Framework, and Imam's Agile Architectural Framework. This step involves a critical review to understand each framework's principles and to assess their relevance to current architectural challenges. Following the theoretical review, the paper then focuses on applying these frameworks to three tactically selected case studies: the new Calgary Central Library, MacKimmie Tower, and Habitat 67. These case studies are analyzed through the lens of the aforementioned frameworks, assessing their applicability and effectiveness in practical scenarios. This comparative analysis is to identify the strengths and limitations of each framework in real-world applications.

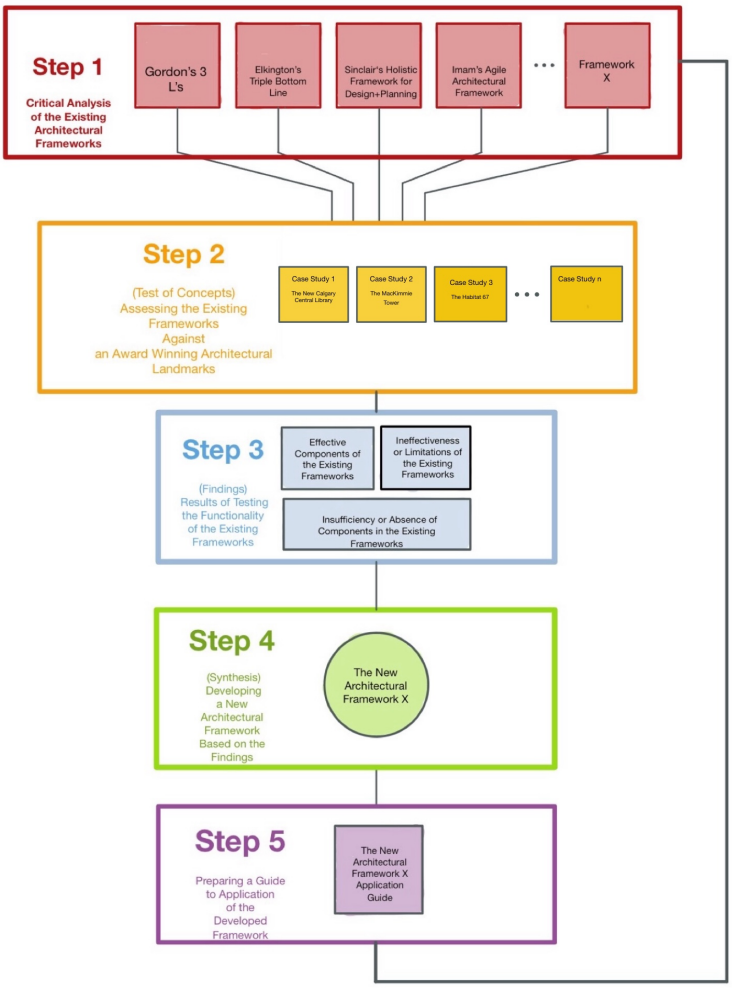


Figure 2: The Five-Step Methodological Diagram. Source: (Bahonar and Sinclair 2024)

The findings from this analysis are then synthesized to conceptualize the Transformation Framework. This synthesis involves integrating the effective elements of the reviewed frameworks while addressing their identified gaps. The Transformation Framework is posited as a more comprehensive, adaptive, and responsive model to modern architectural needs. Lastly, the paper aims to outline the potential application of said framework in architectural practice, demonstrating its utility in addressing the complexities of contemporary design challenges. This methodology aims to make a balance between theoretical examination and practical application and to provide a robust foundation for the development of a new architectural framework.

3.0 MAPPING PARAMETERS AND IDENTIFYING POTENTIAL GAPS IN EXISTING FRAMEWORKS, A CASE-CENTRIC ANALYSIS

In launching this comprehensive section, we probe into a series of architectural principles, as discerned in the designs of the New Calgary Central Library (CCL), MacKimmie Tower, and Habitat 67. These principles, emerging from an extensive research study, are not only pivotal in the creation of the new framework but also exhibit various levels of integration within these architectural case studies. This examination enriches our understanding by dissecting each principle, providing a thorough analysis of their application within and influence upon these landmark projects. The approach adopted here ensures that every principle is carefully considered, both in isolation and as part of a cohesive architectural narrative, thus forming a detailed and meaningful exploration of modern architectural design and its frameworks.

3.1. Sustainability

In architectural sustainability, the emphasis is to minimize the environmental footprint throughout a building's lifespan. This approach prioritizes efficient use of resources while considering both ecological and societal impacts (Bennetts et al. 2003). In that regard, sustainability includes environmental stewardship, regenerative resources, and lifecycle impact, in modern architectural design.

3.1.1 Environmental stewardship: The new Calgary Central Library, with its use of green building materials and energy-efficient systems, exemplifies a commitment to environmental sustainability, a hallmark of contemporary public architecture. The new Calgary Central Library's design, targeting LEED Gold certification, features sustainable elements like low-iron glazing and triple glazing for enhanced thermal efficiency, alongside a skylit

atrium for natural illumination, exemplifying its commitment to Environmental Stewardship (Schwartz 2017) (Snøhetta 2023).
3.1.2. Regenerative resources: MacKimmie Tower's renovation, targeting LEED Gold certification, incorporates solar energy systems and other passive climate techniques such as natural ventilation, heat recovery and thermal mass, showcasing the importance of regenerative resources in educational buildings (DIALOG 2024).
3.1.3 Lifecycle impact: Habitat 67, with its long-lasting modular design, emphasizes the concept of lifecycle sustainability in residential architecture, demonstrating the need for durable and enduring structures (Baker 1997).

Upon examining the architectural frameworks, Sinclair's Holistic Framework addresses these aspects of sustainability under “durability”, “resources” and “balance natural | built” action areas focusing on environmental consciousness and sustainable practices. Also, Gordon's 3L's, aligns with the "low energy" and "long life" aspects, which can be interpreted as regenerative resources and long Lifecycle Impact. Elkington’s Triple Bottom Line, covering sustainability broadly, with its spatial focus, briefly touches upon these specific elements of sustainability in architectural design. Imam's Framework, as outlined in his work on advancing agility in the built environment, prominently feature sustainability as a central theme. Within its structure, the framework addresses sustainability in various subsections, touching on key aspects such as energy balance, the use of reused materials, and principles of the circular economy. These elements are indicative of a comprehensive approach to sustainable design, emphasizing resource efficiency and environmental responsibility in architectural practice.

3.2. Adaptability and flexibility

According to Estaji (2017), researchers and architects use the term *flexible* to describe physical changes and *adaptable* to describe non-physical changes. In other words, the ability to utilize space variously without making physical changes can be defined as adaptability. In contrast, flexibility refers to modifying the physical form of space (e.g., splitting, joining, extending, and merging spaces). It is common, however, for physical and functional changes to occur simultaneously (Estaji 2017).

3.2.1. Modularity: Modular design is characterized by prefabricated units that can be easily assembled, reconfigured, or relocated, allowing for flexibility in the use of space. Habitat 67 stands as a prominent example, with its prefabricated concrete modules offering various configurations to accommodate different living needs. This innovative approach to residential architecture exemplifies the practical application of modular design, enabling the building to remain functional and relevant over time (Baker 1997).
3.2.2. Future-proofing: In the MacKimmie Tower's renovation, future-proofing can be its adoption of a responsive façade system. This system adjusts to external environmental conditions, optimizing energy efficiency and interior comfort, thereby demonstrating a forward-thinking approach in architectural design to accommodate future environmental and technological developments (DIALOG 2024).
3.2.3. Space utilization: A notable example of effective space utilization in the Calgary Central Library is the multi-functional design of its interior spaces. The library features areas like the dynamic, configurable performance hall, which can be transformed for various events, from community gatherings to educational workshops. This versatile design approach exemplifies the library's commitment to maximizing space efficiency and adapting to diverse community needs (Snøhetta 2023).

While the frameworks of Sinclair and Imam specifically address similar aspects of adaptability and flexibility, Elkington’s and Gordon's frameworks provide a broader, albeit less focused, perspective on these qualities. This analysis highlights the need for the Transformation Framework to integrate a nuanced understanding of adaptability and flexibility in architectural design.

3.3. Resilience

Resilience in architectural design ensures structures can withstand and adapt to both short-term disruptions and long-term changes (Liu et al. 2010).

3.3.1. Adaptive design: Adaptive design in architecture provides the capability to modify structures for new uses or to meet changed conditions without extensive redesign or reconstruction. Habitat 67's innovative approach, featuring modular units that can be reconfigured, showcases a level of adaptability crucial in modern architecture. This modular concept seemed to be ahead of residential norms and remains a benchmark for adaptive design in residential architecture even now (Baker 1997).
3.3.2. Structural integrity: The new Calgary Central Library's structural design, featuring a dynamic, geometric exoskeleton, provides not only aesthetic value but also structural robustness, a key aspect of architectural resilience. The use of innovative load-bearing structures in the library demonstrates a commitment to lasting structural integrity (Snøhetta 2023).
3.3.3. Disaster mitigation: The MacKimmie Tower, particularly in its recent renovations, includes seismic retrofitting, a critical feature in disaster-prone regions. This proactive approach toward disaster mitigation is pivotal for modern buildings located in seismic zones (DIALOG 2024).

Sinclair's Holistic Framework generally supports the principle of resilience, particularly through aspects of environmental design that ensure a building's endurance and adaptability. Gordon's 3L's Framework does not explicitly address disaster mitigation or adaptive design, but its "long-life" principle indirectly supports the idea of structural integrity and resilience. Elkington’s Triple Bottom Line broadly encompasses resilience under the umbrella of sustainability, although it may not specifically detail strategies like disaster mitigation. Imam's Agile Architectural Framework is the most aligned with the principle of resilience, especially under the subsection of durability, given its focus on agility and the capacity for buildings to respond to change.

3.4. Human-centric design

The principle of Human-Centric Design, arguably overdue and imperative in contemporary architecture, encompasses health and well-being, user comfort, and accessibility. This approach is integral to creating spaces that are not only functional but also promote the quality of life for their users.

3.4.1. Health and well-being: This subprinciple focuses on designs that promote the physical and mental health of occupants. Habitat 67, with its emphasis on natural light and community spaces, reflects a design that considers the well-being of its residents (Baker 1997).
3.4.2. User comfort: Comfort in architectural design involves creating environments that are pleasant and conducive to the needs of the users. The Calgary Central Library's design, featuring ergonomic and user-friendly spaces, exemplifies the principle of user comfort.
3.4.3. Accessibility: Accessibility, broadly understood and deployed, ensures that buildings are responsive to and usable by people of all abilities. The MacKimmie Tower's renovation includes features to enhance accessibility, such as barrier-free access and user-friendly navigation, reflecting an inclusive approach to architectural design.

While each framework addresses human-centric design to some extent, Sinclair's and Imam's frameworks explicitly focuses on these sub-principles, underscoring the importance of designing spaces that cater to the physical and psychological needs of users. Gordon's 3L's Framework, while not explicitly focusing on human-centric aspects, indirectly supports them through its principle of "loose fit," allowing for adaptable spaces that can meet various user needs. Elkington's Triple Bottom Line encompasses these aspects under its social sustainability dimension, focusing on the well-being and comfort of communities and individuals. This analysis highlights the need for the Transformation Framework to integrate a nuanced understanding of human-centric design, ensuring that architectural projects are not only environmentally and economically sustainable but also deeply attuned to the human experience.

3.5. Community and culture

The principle of Community and Culture, encompassing social cohesion, cultural heritage, and inclusive spaces, impacts how structures integrate into and enhance their communities in architecture. This principle emphasizes the role of architecture in fostering community engagement and preserving cultural heritage, ensuring spaces are culturally welcoming, accommodating, and inclusive to all.

3.5.1. Social cohesion: This subprinciple focuses on creating spaces that encourage community interaction and social connections. Habitat 67's design fosters community interaction through its unique layout and shared spaces (Safdie 1967). The Calgary Central Library serves as an exemplar, with its design facilitating community gatherings, events, and social interactions, thus strengthening social cohesion.
3.5.2. Cultural heritage: This principle indicates on respecting and incorporating cultural heritage in architectural design. The Calgary Central Library incorporates indigenous art and design elements, reflecting cultural heritage.
3.5.3. Inclusive spaces: This facet defines designing spaces that are socially accessible and welcoming to all members of the community, regardless of their background or abilities. This concept goes beyond physical accessibility, focusing on fostering a sense of belonging and community engagement for everyone. MacKimmie Tower, in its design for inclusive spaces, focuses on creating areas that encourage collaborative learning and interaction among a diverse student and faculty population. These spaces include group study areas, seminar rooms, and communal lounges. These areas are designed not just for academic purposes but also to foster social interaction, allowing people from different backgrounds and disciplines to engage, exchange ideas, and build a sense of community.

Each case study illustrates a unique application of the Community and Culture principle, revealing varying degrees of emphasis in the existing frameworks. The integration of community and culture in architectural design is variably represented across these frameworks, with each offering unique insights into how buildings can serve as catalysts for social cohesion, cultural preservation, and inclusivity. Sinclair's Holistic Framework covers these aspects to some extend under the 'Diversity' Action area as 'Mix of Users', emphasizing the importance of cultural and social considerations in design. Gordon's 3L's Framework, while not explicitly addressing community and culture, under the *loose fit* principle indirectly supports spaces that can cater to diverse cultural and community needs. Elkington's Triple Bottom Line similarly addresses these concerns through its social sustainability dimension, emphasizing the importance of community engagement and cultural preservation. Imam's Agile Architectural Framework, with the subsection of community engagement under social wellness, travels in directions that support the creation of inclusive and culturally sensitive spaces.

3.6. Technology and innovation

This principle focuses on integrating advanced technological solutions into architecture for enhanced functionality and greater efficiency.

3.6.1 Digital integration: This subprinciple refers to the seamless incorporation of digital technologies into the fabric of building design to enhance user interaction and operational efficiency. A structural example of digital integration in the Calgary Central Library is its RFID (Radio-Frequency Identification) system. This technology enhances user interaction and operational efficiency by streamlining the borrowing processes (Snøhetta 2023).
3.6.2. Smart systems: Smart systems involve the use of intelligent automation and control processes to manage building operations, which can significantly improve energy efficiency and user comfort. A good example of smart systems in MacKimmie Tower is its advanced building automation system. This system intelligently controls heating, ventilation, air conditioning (HVAC), and lighting to optimize energy use and enhance occupant comfort (DIALOG 2024). The integration of sensors and automated controls allows the building to adjust to different occupancy levels

and environmental conditions, significantly improving energy efficiency while maintaining a comfortable and adaptive learning environment.
3.6.3 Performance analytics: This quality involves using data-driven approaches to optimize building performance. The MacKimmie Tower, with its focus on sustainable renovation, employs advanced analytics to ensure its new features, such as solar energy systems, perform optimally and contribute to the building's overall energy efficiency.

Each of the four frameworks under study offers varying degrees of alignment with the principle of Technology and Innovation, highlighting the evolving role of technology in architectural design. Gordon's 3L's Framework, while not explicitly focusing on technology, aligns with the principle through its "low energy" aspect, which can be achieved through smart systems and performance analytics. Elkington's Triple Bottom Line supports the integration of technology as part of achieving sustainable development goals. Sinclair's Holistic Framework indirectly addresses these technology and innovation subprinciples in its 'Agility' action area, highlighting the importance of adaptability and responsiveness in design, which can be enhanced through technology. Imam's Agile Architectural Framework under the 'Technological Flexibility' section directly correlates with this principle, advocating for the use of advanced technologies to enhance the agility and adaptability of architectural designs.

3.7. Economic and ethical responsibility

This principle addresses the balance between economic sustainability and ethical considerations in the pursuit of potent and appropriate architectural design.

3.7.1. Economic viability: This subprinciple involves designing buildings that are financially sustainable over their lifespan. For instance, the Calgary Central Library, with its multifunctional spaces, represents an economically viable model by serving various community needs, and enhancing its long-term value.
3.7.2 Ethical materiality: Ethical materiality focuses on using materials that are sustainably sourced and environmentally friendly. The MacKimmie Tower's renovation, given its LEED certified status, includes eco-friendly materials, exemplifies this commitment to ethical materiality (DIALOG 2024).
3.7.3 Long-term value: Long-term value in architecture refers to creating buildings that remain valuable and functional over time. Habitat 67's innovative design, which has remained iconic and functional for decades, demonstrates this principle by providing lasting architectural value.

Sinclair's Holistic Framework Under the 'Agility' main Action area defines 'Materiality', 'Durability', 'Constructability', and 'Adaptability', which holistically encompasses Economic and Ethical Responsibility to some degree. Gordon's 3L's Framework, while focusing on "long life," may indirectly relate to economic viability and long-term value but does not explicitly address sub-principles such as ethical materiality. Elkington's Triple Bottom Line addresses economic and ethical responsibility by integrating economic, social, and environmental dimensions in its sustainability approach. Imam's Agile Architectural Framework, though primarily focused on adaptability, implicitly under several sub-sections supports these aspects by advocating for responsible and sustainable design practices.

3.8. Disaster preparedness

This principle is crucial for ensuring that architectural designs are prepared for potential disasters, over a wide-reaching array, focusing on risk management and recovery.

3.8.1. Risk assessment: With its recent renovations focusing on sustainability and modernization, MacKimmie Tower includes risk assessment elements appropriate to its urban university campus setting. This involves fire safety enhancements, structural integrity measures for seismic activity, and systems to manage environmental risks such as extreme weather conditions (DIALOG 2024).
3.8.2. Emergency response: Emergency response planning in architecture ensures buildings are equipped to handle crisis situations effectively. The new Calgary Central Library's emergency responses, given its advanced construction, includes fire safety protocols, evacuation procedures, emergency communication systems, and areas designated for shelter during crise.
3.8.3. Recovery planning: This subprinciple focuses on designing buildings that can quickly recover from disasters with minimal disruption. Habitat 67, given its unique modular construction, may have considerations for recovery and rebuilding in the event of a disaster, ensuring minimal impact on residents (Safdie 1967).

While none of the frameworks comprehensively or explicitly address the principle of disaster preparedness, they each touch upon related aspects in different ways. Sinclair's Holistic Framework indirectly addresses disaster preparedness, particularly under the aspects of durability and adaptability, ensuring buildings can withstand and recover from disasters. Gordon's 3L's Framework, with its emphasis on *long-life*, indirectly supports disaster preparedness by advocating for durable and resilient structures. Elkington's Triple Bottom Line encompasses these aspects under its environmental sustainability dimension, highlighting the need for ecological resilience. Imam's Agile Architectural Framework, while primarily focusing on agility, under several subsections indirectly supports disaster preparedness through its emphasis on adaptable and responsive design.

It is important to mention that the case studies selected within Canada were chosen for their proximity to and 'engage-ability' by the authors, allowing for personal exploration and a deeper understanding of their impact on users. These architectural landmarks are not only nationally recognized but have also gained international acclaim, winning prestigious awards for their innovative and impactful designs. These landmarks, celebrated for their design excellence, exemplify the essence of 'good architecture' as delineated by Sir Alex Gordon's principles of loose fit, long life, and low energy -- which today translates into the attributes of durability, flexibility, and sustainability (Imam 2022). While these studies offer in-depth insights, the principles discussed are universally applicable, extending far beyond Canadian borders to reach architectural projects worldwide.

Moreover, the intersection of principles identified in this speculative and provocative discourse is reflective of the intricacies inherent in contemporary architecture. The contemporary architectural landscape, characterized by its multifarious demands, necessitates frameworks that transcend mere comprehensiveness to achieve specificity and detail. This characteristic is important for articulating distinct yet overlapping architectural themes, ensuring that each principle, while potentially intersecting with others, maintains its unique contribution. This approach enables a nuanced understanding of complex architectural challenges, ensuring that emergent frameworks are not only robust and adaptable but also meticulously tailored to address the varied dimensions of today's urban and architectural contexts.

CONCLUSION: INITIATING THE CONCEPT OF NEW AGILE + HOLISTIC ARCHITECTURAL FRAMEWORK (THE TRANSFORMATION FRAMEWORK)

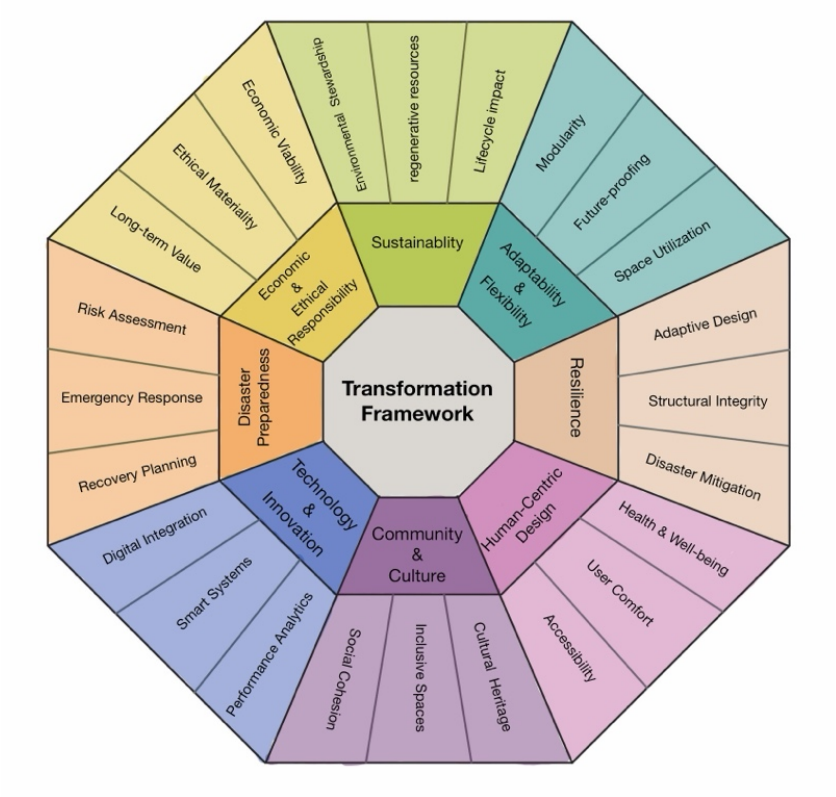


Figure 3: The Transformation Framework Diagram. Source: (Bahonar and Sinclair 2024).

As this paper draws to a close, it becomes imperative to encapsulate the essence of the *Transformation Framework* – a novel architectural paradigm that emerges from a confluence of insights gleaned from existing frameworks, enriched by the nuanced analysis of our critical case studies: the Calgary Central Library, MacKimmie Tower, and Habitat 67. The Transformation Framework transcends traditional architectural boundaries, embodying agility and holism as its core tenets, thereby addressing the multifaceted challenges of contemporary design. The inception of the Transformation Framework is rooted in the critical examination of Gordon's 3L's, Elkington's Triple Bottom Line, Sinclair's Holistic Framework, and Imam's Agile Architectural Framework. Each of these seminal frameworks, while instrumental in their own right, collectively reveal certain gaps when juxtaposed against the dynamic demands of modern architecture. The Transformation Framework, thus, emerges not only as a creative amalgamation of these models but, more strategically, as a refined synthesis of same, meticulously crafted to plug gaps, to proffer more cohesion, to stand as more adaptive, and to assume a posture that is forward-looking with respect to architectural design.

The Transformation Framework, while in its nascent stages, is not the sole focal point of the present research. Instead, it represents a specific culmination of a deeper exploration and opening understanding of architectural needs in a rapidly changing world. The journey to the Transformation Framework highlights a fundamental and pressing need for more nuanced, adaptable, and comprehensive approaches to architectural design, one that acknowledges the complexities today's urban environments and the richness of today's societies. The principles distilled from the analysis of existing frameworks and prominent case studies – sustainability, adaptability, human-centric design, resilience, technological integration, and ethical responsibility – form a complementary and compelling mosaic of insights. These insights, while instrumental in shaping the proffered framework, also stand independently as guiding beacons for contemporary architectural practices.

In essence, the journey to and beyond the Transformation Framework is a testament to the evolving nature of architectural design. It is a call to embrace complexity, to navigate change via agility, and to craft spaces that resonate with both the current zeitgeist and future aspirations. As the study, and its conceptual frame, reaches the current marker, it leaves open the possibilities for further refinement and evolution, inviting continued exploration

and innovation in the architectural field. Our times are fragile in many ways, yet promising in others. Design matters across a dramatic swath of our lives, over a plethora of our built spaces and occupied places, and in ways that significantly impacts health and happiness.

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DISCIPLINARY AND INTERDISCIPLINARY APPROACHES

Rethinking the home office: Teleworking mothers' material housing adaptations during COVID-19

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ABSTRACT: This follow-up qualitative study delves into the contribution of housing on the material adaptations of teleworking mothers during the COVID-19 pandemic. The investigation concentrates on the interplay between housing conditions, the multifaceted challenge of daily routines faced by mothers, and telework setups during stay-at-home orders. Insights from the adaptation process will inform flexible design criteria for home offices in the context of a global telework upsurge and enhance preparedness for future emergencies. Narrative accounts were gathered through 33 semi-structured Zoom interviews of teleworking mothers, supplemented by annotated architectural plans. AI-assisted discourse analysis using ChatGPT-4.0 was conducted on four groupings defined by comparable residential situations (defined along housing attributes, family structure, and work modality profiles). Floor plans, dwelling pictures from home offices or multifunctional spaces, participant profiles, and interview extracts were used for a thorough architectural assessment and for uncovering each group's material adaptations. The findings were subsequently verified through qualitative analysis. Key design strategies for future housing projects and renovations to improve work modality transitions and telework productivity, especially when living in apartments or with small children, are the inclusion of flexible multifunctional rooms, quiet areas with foldable desks, portable home office setups for the self-employed on the move, small home offices for occasional meetings in sub-utilized storage rooms, modular and soundproof partitions temporarily separating open plans or shared home office spaces, visual partitions to demarcate private and work environments, designing office spaces in intermediate and exterior areas like verandas and balconies through the inclusion of glassed perimeters for winter use, and planning adaptable building systems.

KEYWORDS: COVID-19, residential situation, adaptation, design guidelines, mental health.

1.0 INTRODUCTION

1.1 Pandemic and telework: residential architecture in transition

While telecommuting is not a new phenomenon, residential projects have begun to incorporate flexibility criteria to facilitate working from home (Bettaieb and Alsabban 2020; Yaneva 2022), with popular magazines and architects' firms advising on the best ways to create a home-office (DK Studio 2021; Rajendrakumar 2023). The U.S. Government Accountability Office reports that, in 2021, exclusive telecommuting, i.e., when the worker completes all work tasks from home, increased from 5.7% in 2019 to 17.9% in 2021, and partial or hybrid telecommuting, when some tasks are performed from home, increased from 23.7% to 38.1%. However, this increase was mainly concentrated in certain industries, especially those linked to information, and among people with higher salaries (Government Accountability Office 2023), conducive to hybrid telework modalities (Carrasco-Garrido, De-Pablos-Heredero, and Rodríguez-Sánchez 2023). One of the direct consequences of telework's growth is that the real estate market must incorporate home offices in residential projects, especially for those targeting middle-to-high earners. Public policy will also need to find ways to incentivize the transformation of the existing housing stock to incorporate multifunctional office space.

Women carry a significant part of the household burden (Hilbrecht et al. 2008; Morin, Fortier, and Deschenaux 2018), and during the pandemic, there were no exceptions (Craig 2020; Kofman and Garfin 2020; Pasqualini et al. 2022). Even in progressive societies such as Canada, women were at the center of household adaptation efforts (Cockayne 2021; Fuller and Qian 2021; Tremblay and Mathieu 2020). Moreover, the adaptive difficulties of the mothers in the study are a critical pillar for residential design improvements because of the impact their mental and physical health has on families (Freisthler et al. 2021; Heilman and Calarco 2022; Statistics Canada 2022). The research presented in this paper focuses on the difficulties of teleworking mothers during the pandemic as well as on identifying how residential architecture can make their everyday lives easier and more comfortable, especially in times of lockdown, equally contributing to an existing pool of COVID-19 research applicable to future crises with stay-at-home orders (Alhusban, Alhusban, and Alhusban 2022; Aramayona and Nofre 2021; El-Husseiny 2021; Yaneva 2022).

1.2 Research question and objectives

Considering these developments, how can the adaptations of teleworking mothers during the COVID-19 pandemic inform future residential design to safeguard mental health and improve work-life balance? From this question, the two main objectives follow. First, to investigate teleworking mothers' adaptations in varied residential situations and

with different mental health profiles. Second, to identify design strategies enabling telework during crises (Alhusban, Alhusban, and Alhusban 2022; Downing 2016; Hagar 2012) and improving telework conditions in the context of a burgeoning information society (Castells 1996; 2001).

2.0 THEORETICAL AND CONCEPTUAL FRAMEWORK

Similar to Sweet & Scott (2022), here the term telework is used as a synonym for home-based work. The use of the term does not include other out-of-home locations for work, like cafes or coworking environments. It does not include third or fourth places, despite the potential benefits of developing teleworking spaces within them (Aelbrecht 2022; Williams and Hipp 2019). The term adaptation is used from the point of view of the material, behavioral and cognitive modifications necessary to meet the objective of routine continuity and coping with stressors, specifically in the case of working from home (Alves, Amorim, and Bezerra 2021; Ayuso et al. 2020; Barahona 1983; Guilloux et al. 2021; Hizra, Dewi, and Izziah 2021; Lloyd 2021; Platt 1970; Simonet 2009; Viriot Durandal et al. 2018). Finally, the term vulnerability is used from the perspective of potential coping difficulties, not immediately implying a scarcity of economic resources. It means a complex situation where a lack of resources may be one of the elements combining to generate crucial adaptation difficulties (Doucet, Turman, and Diwan 2021; Raynor and Panza 2021; Robinson et al. 2021; Vergara-Perucich, Correa-Parra, and Aguirre-Nuñez 2020). In turn, adaptation difficulties are potentially linked to a lack of personalization opportunities, hindering its well-being-enhancing properties (Al-Tarazi et al. 2024).

3.0 METHODOLOGY

3.1 Qualitative data collection

The research took place in the province of Quebec, Canada, and interviews were conducted by ZOOM using a subsample of teleworking mothers (n=33) selected from a previous mixed method study employing Multiple Factor Analysis (MFA) on a sample of 538 women with children at their dwelling. This previous study identified four key subgroups representing common residential situations in the sample (showcasing common residential situations defined by housing attributes, family structure, and work modality profiles), which served as a starting point for this paper's qualitative analysis section. All participants in both projects are part of the comprehensive MAVIPAN database (CIUSSS de la Capitale-Nationale 2023; LeBlanc 2021). The study utilized data from 33 interviews with teleworking mothers collected through semi-structured ZOOM interviews (Archibald et al. 2019; Oliffe et al. 2021). Participants discussed their telework or distance learning arrangements (in the case of student mothers) during the pandemic, with a focus on lockdowns. The four groups identified were the following.

1. Young single-parent or recomposed family mothers living in apartments, which encapsulates participants navigating complex family structures.
2. Self-employed mothers with young children, including lower-than-average dwelling occupation density for most participants.
3. Studying and working on-site mothers with children are indicative of participants with a medium gross household annual revenue (50,000-79,999 CAD) and higher-than-average dwelling occupation densities.
4. Self-employed middle-income mothers in small dwellings comprise individuals of average ages and average dwelling occupation densities.

These four groups became the focus of the qualitative analysis section, as telework material adaptations regarding their home-office setups were researched. All except one participant submitted a drawing of the architectural layout of the dwelling. Photographs of living spaces complemented these plans by 27 participants, which allowed for material changes and home modifications to be drawn on top of each plan live during the interviews. The interview -based on a 38-point questionnaire - delved into participants' daily routines, focusing on how they organized telecommuting and distance learning.

3.2 AI-assisted thematic analysis

Additionally, this work combines the use of artificial intelligence through ChatGPT-4 for qualitative analysis -without losing sight of its limitations (Ayub et al. 2023; Khlaif et al. 2023; Kocoń et al. 2023)- and traditional qualitative analysis based on grounded theory (Glaser and Strauss 2017; Uri 2015) emphasizing user perspectives (Clarke 2005), demonstrating the compatibility of new AI-assisted tools with qualitative methodologies, enriching the field of architectural research (Groat and Wang 2013). The methodology was developed with an equally design-oriented vision, which constitutes an interdisciplinary contribution linking social science research with design science (See Appendix C).

Using both text and images, the AI was asked for adaptation patterns showing how each group of working mothers progressively created home offices within their dwellings. In the first step, the model was provided with the floor plan, along with dwelling and home-office photographs, of each participant individually, complemented by interview text detailing the teleworking setup and tele-studying setup when relevant. The model was then tasked with providing an architectural assessment for each participant separately, analyzing their dwelling's architecture during material telework adaptation. The resulting output had three parts. First, an evaluation of the positive and negative aspects of the participant's dwelling architecture, a flexibility assessment, and a description of the participants' adaptation accounts. The two last elements were used to construct separate scores for flexibility and adaptation effort: 1 for low flexibility and low adaptation effort, 2 for moderate flexibility and moderate adaptation effort, and 3 for high flexibility and high adaptation effort. A Microsoft Excel document was constructed using the architectural assessment for in-depth verification and comparison.

All 33 architectural assessments were then re-submitted together in a single document, except pictures and plans, for the model to find participant adaptation patterns according to the MFA groups. The four sub-groups from the MFA were described in the instructions, requesting that the model use them for theme finding, concentrating on material adaptations to telework.

4.0 RESULTS AND DISCUSSION

The present section is articulated in three steps. First, presenting and discussing the architectural assessment and its verification, then proceeding with telework adaptation patterns obtained using ChatGPT-4 for each of the four sub-groups previously identified. The discussion closes with a final section on general housing design guidelines springing from the complete analysis.

4.1 Architectural assessment

The architectural assessment results were accurate, with deep spatial analysis. The model captured themes from participants' needs, showing precise reflection after checks. It detailed the positives and negatives of each residence's architectural layout, considering specific household types, i.e., apartments, multi-generational dwellings and loft studios, and multi-floor homes. For example, the output explained the case of a single mother who faced challenges with her office on the ground floor, away from her children's desks upstairs, affecting supervision. However, errors occurred with 5 participants with complex, non-standard information, like those who moved during the pandemic. These errors underscore the model's need for consistent data, often lacking in semi-structured interviews. Table 13 shows that Group 2 had higher flexibility scores, while Profiles 1 and 4 scored lower. Profile 3 had varied scores due to their diverse needs as students and workers. Apartments were less flexible, but all groups showed significant adaptation efforts, proving people's resourcefulness in improving their living and teleworking spaces. Interestingly, those with more resources also made significant adaptations, maximizing their dwellings' flexibility.

The existence of significant adaptation efforts in all groups shows that people used the resources available to them to improve their residential situations and teleworking arrangements. Contrary to the belief that participants with more resources would potentially make fewer adaptations, this shows that they were probably maximizing the opportunities conferred by their dwelling's flexibility. In other words, more flexibility is desirable since it channels adaptation efforts more smoothly.

Table 1 Flexibility and adaptation effort scores. Source: (Authors' tables 2024).

		Flexibility Score			Total
		1	2	3	
MFA Group	1	1	2	0	3
	2	0	2	4	6
	3	1	3	2	6
	4	2	4	2	8
	Outliers	1	7	2	10
Total		5	18	10	33

		Adaptation effort Score			Total
		1	2	3	
MFA Group	1	0	2	1	3
	2	0	3	3	6
	3	1	3	2	6
	4	2	1	5	8
	Outliers	2	3	5	10
Total		5	12	16	33

Cluttered spaces were an important theme. They are unproductive due to distractions or saturation. Clutter complicates transitioning to telework via decreasing well-being (Rogers and Hart 2021), suggesting that covering open shelves and helping organize office material in proper compartments is a safe design strategy both for telework productivity and shielding mental health. A significant theme addressed is the mental health of participants and its link to adaptation efforts. The assumption is that mental health issues complicate daily life over time, slowing adaptation. This phenomenon was partly verified within the sample of teleworking mothers, effectively seen in participants who were significantly stressed at the pandemic's start or those experiencing unfortunate events like winter falls and severe health issues. Their accounts evidence a sustained and prolonged adaptation effort which was qualified as slow or insufficient.

4.2 Results across four profiles

Profile 1. Young single-parent or recomposed family mothers living in apartments faced unique challenges. They creatively adapted to small spaces, often shared with children, which required innovative solutions. Adjusting work hours has been crucial to balance their professional and familial duties, with many opting for flexible work schedules. Childcare is a significant concern, with reliance on family members or friends for support. Noise management from work tasks and children's activities presented a challenge, leading to the need for multifunctional spaces that serve both work and family purposes.

Profile 2. Self-employed mothers with young children developed specific strategies to manage their dual roles. Establishing a dedicated home office is a common approach to maintaining productivity. Childcare assistance, either through professional services or family help, is crucial during work hours. These individuals typically adhere to structured work hours to efficiently balance their business commitments and childcare. Many have adopted hybrid work, i.e., they constantly shift from their home office to their traditional workplace. By combining telework with on-

site operations, enabling efficient supervision of employees, their storage and communication needs must address a certain level of standardization to keep transitions smooth.

Profile 3. Studying and working on-site mothers with children balanced on-site work, study, and childcare. A significant support system comes from extended family networks that assist with childcare during working hours. Synchronizing work and study schedules with their children's routines helps minimize schedule conflicts. Utilizing breaks during the workday to spend time with their children is a common practice that solicits design flexibility.

Profile 4. Self-employed middle-income mothers in small dwellings have their unique set of practices. Many have established dedicated home offices to create a professional workspace within their living quarters. The flexibility of self-employment allows them to adjust work hours as needed to accommodate personal and family requirements, thus minimizing the impact on family life. Some choose to occasionally work from third places to maintain a clear separation between their professional and personal lives, probably highlighting a need for work-life balance.

4.3 Material adaptations

Profile 1 participants relied heavily on technology for space management and the utilization of communal areas in their apartments, with consequences on home material culture (Clark and Lupton 2021; Watson, Lupton, and Michael 2021). The risk of heightened technology use and dependence had been researched before (Baillie and Benyon 2008; Berkowsky 2013; Glucksmann and Nolan 2007), showing that women's roles as mothers and workers can be strained. As expected, this was problematic when resources were scarce or when daycare centers closed. Those in old apartments with low flexibility experienced adaptation difficulties, leading to quality concerns in the case of student participants (Francis and Weller 2021). For Profile 2, material adaptation involved the transformation of different home areas into multifunctional spaces and professional offices to cater to various needs, protecting these participants from mental health impacts when compared to Profiles 1 or 4. When compared to all other groups, Profile 2 participants showed an interest in customizing their office spaces with a professional taste, probably reflecting their roles as business owners, not just as workers. In Profile 3, participants created specific work and study areas within their medium-sized dwellings, emphasizing the importance of noise-canceling devices to maintain productivity and focus during on-site work and online education. Profile 4 participants adapted smaller spaces for work, and some sought external spaces for relaxation, recognizing the limitations of their small dwellings and apartments size and layout. For more details on each profile's adaptations, see Appendix G.

Teleworking involves the creation of workspaces for mothers and their children when distance learning (Andrada-Poa, Jabal, and Cleofas 2022). Mothers had to find new ways to free up space for the use of digital communication technology (Tavares et al. 2021). Nevertheless, supervision was needed in the case of small children, so this often meant being able to have a view from their home office of their children's workstations. This very complex spatial arrangement was nevertheless possible for some. The materiality of the house could lend itself to more flexible adaptation, as has been noted in recent research (Bettaieb and Alsabban 2020). For some low-income participants in Profiles 1 and 2, having few economic resources and an architectural distribution with plenty of open areas, i.e., few partitions and complex families, made things worse, which aligns with the commonalities observed in participants, especially apartment dwellers, belonging to Profile 1. Due to the Province of Quebec's Nordic climate, many participants adapted by using their basements, which solicited renovations, which contributed to adaptation inequalities, as forecasted at the start of the pandemic (Bonacini, Gallo, and Scicchitano 2021), despite research on organization family-friendly measures in the years leading to the pandemic (Mansour and Tremblay 2018).

4.4 Working mothers and telework: Towards design guidelines

Different telework adaptation patterns among various groups of participating mothers underscore the importance of developing a unified set of strategies for home office design (Srivastava et al. 2024). These strategies aim to establish standards that are not only beneficial to mental health but also cater to the diverse needs of different family structures and working conditions. For mothers living in apartments, either single-parent households or in recomposed families, transforming small spaces into additional office areas is crucial for maintaining supervision and family contact, and avoid solitude. These spaces need to be flexible, well-lit, soundproof, and ergonomic, with plenty of storage space and flexibility. In the case of self-employed teleworking mothers with young children, the preference for hybrid work models necessitates dedicated and professional home offices with visuals of children's rooms or family areas. Incorporating fenestration is essential for a calming effect and stress reduction. Their storage needs are high due to the multiple tasks they accomplish within their companies and the need for a very professional image tied to their managerial roles.

For those self-employed mothers (profiles 2 and 4), a professional and portable home office environment is essential, particularly for those engaged in frequent meetings and who occasionally work from third places, implying movement. This strategy includes well-ventilated, ergonomic, and soundproof spaces. The basement can be used for teleworking if well equipped, especially as a way of creating a spatial boundary to enhance work-life balance. In the case of studying mothers with young children, some working on-site, design solutions should focus on convertible spaces, modular partitions, and multiple office nooks to accommodate familial, personal, and professional adaptations involving multiple roles and changing needs, with clutter reduction capabilities. Occasional breaks mean their office spaces should be easily transformed. Office supplies should be easily stored, and if possible, the modular space should be transformed for another use, including the possibility of storing screens or computers in custom storage spaces.

From these considerations, the following design and specification criteria are suggested.

1. Multifunctional spaces. The dwelling unit should include flexible and multifunctional office spaces, with an emphasis on modular furniture that can be transformed for other uses during breaks. Consider integrating hinged tables in areas like stairs or living rooms and avoid placing office furniture in bedrooms unless a movable separation is feasible.
2. Quiet Zones and Quiet Nooks. Incorporate both open and closed quiet zones using sound-absorbing materials for walls, ceilings, and partitions. Consider movable, modular barriers for flexibility in the guise of pivoting partitions and doors and temporary visual interruptions as cues for other members to know the zone is being used.
3. Basement Office Spaces. Basements can be utilized for office spaces for emergency situations, especially those with half windows. For basements without fenestration, use soothing colors, ambient lights, and plants to enhance the environment. To enhance work-life balance, use different colors and motives accentuating the difference with the ground floor.
4. Innovative Small Office Spaces. Transform small, underused spaces into multifunctional, soundproof office areas for occasional use. This transformation can be accomplished using underused closets or similar storage areas within existing dwellings. Ensure full isolation in basement areas to avoid future remodeling costs.
5. Open Spaces with Movable Partitions. In open space designs, include movable partitions to separate areas like the kitchen or living room temporarily. Ensure clear visuals from workspaces to common areas and soundproofing.
6. Balconies as Multi-season Offices. Large balconies should be designed to accommodate perimeter glass, enabling their use as multi-season office spaces for Nordic climates.
7. Intermediate Outdoor Spaces. Encourage the use of glass-enclosed verandas or porches to provide well-fenestrated outdoor workspaces for breaks and relaxation. These intermediate spaces are particularly useful for the fast-paced self-employed, allowing them to store office material easily.
8. Dedicated Office for Working Couples. Provide dedicated office spaces with separate L-shaped desks and soundproofing for couples. Include at least one alternative office space for occasional use when meetings coincide during the day or when supervision is warranted in the case of couples with small children.
9. Key Elements for Multifunctional Spaces. Emphasize natural light, cross ventilation, warm materials, ergonomic furniture, soundproofing, and ample storage in all multifunctional spaces, including nooks, balconies, and verandas.
10. Portable offices. The experimental concept of the portable office can be beneficial for those who migrate between their home office and third places. Modular desks with additional screens, set up to easily receive and disconnect laptop computers in various places of the dwelling, as well as storage spaces for briefcases and hard drives or other office supplies, could benefit the self-employed on the move.
11. Adaptability of Residence Systems. Ensure the adaptability of the home's systems, including internet connectivity, electricity, plumbing, and heating, to facilitate their use in various areas like the basement and outdoor spaces.
12. Children's Rooms. Include space for a full-size, functional desk in children's rooms, with lighting outlets on walls for flexibility when the room is used as an office by adult family members or children, which happens often in the case of recomposed families.

CONCLUSION

This study extracted design guidelines by categorizing material adaptations using ChatGPT-4 along four previously identified groups, followed by a detailed qualitative analysis. This sequential approach proved crucial in systematically identifying (Hoyningen-Huene 2013) the diverse adaptation patterns of teleworking mothers, highlighting the necessity to understand user perspectives. As the pandemic progressed, these mothers evolved their telework approach—shifting from viewing the situation as a temporary arrangement to actively modifying their spaces to meet changing needs and expectations. This study ultimately sheds light on the fluid nature of residential architecture, underscoring its need to be responsive to the evolving life circumstances of its inhabitants, particularly in crises like the COVID-19 pandemic and amidst the growing trend of telework.

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Stakeholder Research in Architecture and Urban Design: Assessing Emerging Methods for a Post-Pandemic World

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ABSTRACT: Architecture and urban design represent spatial conceptualizations at different, interlinked scales. Economic and social sustainability as part of the design concept requires user and community-based research to determine stakeholder habits and needs. One of the largest challenges in such research is collecting representative data, a challenge that was exacerbated by the lack of in-person research opportunities during the Covid-19 pandemic.

The pandemic forced research method adaptions for both qualitative and quantitative community-based research. Our paper examines these adaptations as examples of emerging methods more generally. We first summarize both analog and digital stakeholder-focused built-environment research over the past decade. Next, through a literature review, we focus on studies conducted during the COVID-19 pandemic to detail new methods and tools developed during this time. A special focus is on methods developed to access stakeholder groups often overlooked in built-environment research, such as low-income and other vulnerable populations.

We analyze emergent and newly developed methods to determine their applicability, benefits, and limitations for use in a post-pandemic world. In doing so, we contribute to developing methodologies and tools for built-environment stakeholder research where data has typically been harder to access.

KEYWORDS: Emerging Research Methods, Community Engagement, Digital Research Methods, Stakeholder Theory

INTRODUCTION

The Covid-19 pandemic, with its lockdowns and subsequent lifestyle implications, challenged researchers conducting community and urban research. Qualitative field studies that required access to specific sites and population groups became difficult. Researchers operating globally and across disciplines were especially challenged, as travel became impossible.

Research groups quickly organized to provide assistance. The Nippon Foundation Ocean Nexus Center at the University of Washington (Garcia and Barclay 2020) compiled resources on conducting social science-based research despite pandemic constraints, while academic organizations working on spatial research offered workshops on methods that lent themselves to conducting research during lockdowns and travel restrictions (Parikh and Henrique 2021).The *International Journal of Urban and Regional Research* published a collection of essays in which scholars pursuing research on urban communities outlined their pandemic challenges and methodological adaptions (Weinstein 2021). One issue highlighted by these studies is that many methods relied on digital data collection, yet digital access is distributed unevenly across the world, with poorer communities less likely to have access to digital devices or platforms. Researchers became aware that increasing use of digital methods required rethinking the roles of research participants, and that digitalization presented both opportunities and challenges for the research process.

Although digital data collection and analysis methods were prevalent before the Covid-19 pandemic, the pandemic arguably led to an acceleration of such methods. Our assessment of this process will show that researchers creatively employed remote data collection methods using online services or the internet, and that while researchers were often challenged when working with populations without online access, remote data collection methods could also improve access to populations for whom in-person data collection methods had been unsurmountable.

1.0 ANALOG DATA COLLECTION METHODS

1.1 Urban planning and design: soliciting community input

Community engagement has been defined as dialogue and discussion between the general public and the decision-making body (Cavaye 2004). In this process, stakeholders discuss their needs and concerns and negotiate common goals. This engagement may occur at one or multiple stages, from early planning to post-occupancy evaluations. The level of engagement of stakeholders varies based on the methods and phase of engagement in a project.

While community engagement concepts were initially developed in the 1960s, western countries, including many European countries and the United States, accelerated use of such tools in the late 1990s (Lawson and Kearns 2010). Governments and NGOs have published a range of toolkits and guides on engaging communities for inclusive and sustainable development (cf. Futurewise et al. 2014; Sankofa, et al. 2021; Queensland Government 2017; Trans-Urban-EU-China 2020). Methods have included interviews, shared comment boards, in-person and online "walk along" or "ride along" tours to identify community needs, vision and design workshops, and dialogue about draft master plans to gain community recommendations and ideas (Canesi, et al. 2022).



Figure 1: Developing ideas for a community school project through a board-game exercise. Source: (© Baupiloten BDA 2023)

One of the most longstanding forms of community engagement at both the urban and architectural design level is participatory design, where experts (architects, landscape architects, urban designers, and those from related fields) solicit input from future users in the decision-making process (Figure 1). Sherry Arnstein defined the degree of citizen involvement through a seminal "Ladder of Citizen Participation" in 1969. Arnstein's conceptual hierarchy ranged from "nonparticipation", where citizen-stakeholders have no means of participating in planning decisions, to "citizen control", where citizen stakeholders have extensive agency in the planning process (Arnstein 1969). While Arnstein did not define specific methods of citizen participation, her framework continues to provide an evaluative tool for such measures.

Urban development projects often make use of several rounds of citizen participation. As an example, the "Great Park" project in Orange County, California, used extensive citizen solicitation tools in a process that spanned decades. First, ballot measures were proposed to determine large-scale planning ideals. Community leaders and representatives of major area demographics were then invited to participate in focus group interviews as part of a "visioning" process. In a further step, the project planners organized a stakeholder conference, with names suggested by the focus group members. This conference included further visioning exercises based on specific themes such as sports, business interests, education, and so on. Conference participants also filled out two questionnaires and summarized information to develop what for them were the most salient features desired in the park. Information gained at the conference was then used to develop a countywide telephone survey to solicit ideas from a larger group of citizens. As a final step, all Orange County residents were invited to rank the competition proposals developed by the invited design firms. (Garde 2014) Because of the timeframe (the first stages of planning took place from 2002 to 2014), many of these measures were analog or in-person, although several (such as surveys) would likely be conducted online today.

Globally, planning bodies and non-governmental organizations (NGOs) have used community engagement, including participatory methods, as a tool in urban regeneration, city design, tourism planning, and urban planning processes (Bahaire and Elliott-White 1999; Howard and Gaborit 2007; Lawson and Kearns 2010; Canesi, et al. 2022). Lawson and Kearns have called public engagement a means of promoting democracy and empowering communities (Lawson and Kearns 2010). When the community voices are representative of community demographics, this is surely the case. In the Orange County example, an analysis found that representation was spotty: The majority of community members in the participation process were white and affluent; many were senior citizens. The community at large, however, was much younger and proportionately more Hispanic. Additionally, researchers found that business leaders were able to influence public opinion through advertising and other measures (Garde 2014). As we will see below, digital data collection measures can help solicit community input from a more representative cross section of the population, especially in areas where digital access is widespread.

1.2 Interviews, oral histories, and "go-along" methods

Both practitioners and scholars seek understanding about urban context and urban histories. Oral history has been used as a data-collection method to access historical and contextual information about communities where written records are scant. Here, researchers access individual and collective memories of historical events or phenomena

to develop or assess spatial transformations. Interviews are conducted with individuals or groups. Oral history has proven invaluable in indigenous research projects, neighborhood planning with stakeholders, and social justice projects (Thomas 2004; Maharawal and McElroy 2018; Ahrar 2018; Stead, et al. 2019; Selvi Ünlü 2019; Ramiller 2022). This fine-grained and accessible method has especially helped researchers gain information about how historical events have impacted minority communities (Thomas 2004; Virdee 2013; Maharawal and McElroy 2018; Ramiller 2022; Ahmad 2022).

A more extensive method that incorporates both oral history and interviewing is the go-along method, where the researcher accompanies a community member and informally interviews them during their everyday tasks (Kusenbach 2003; Ahrar 2018; Sun and Lau 2021; Veitch et al. 2022). This method has proven especially useful in gathering data from groups such as children or the elderly, where data collection methods such as surveys or focus groups may be challenging (Oliver et al. 2011; Sun and Lau 2021).

As in any in-person data collection, researchers must establish a rapport with participants before data collection begins. Participants must feel comfortable sharing information for data collection to be effective. Experienced researchers are adept at putting research participants at ease before commencing the data collection process itself.

2.0 DIGITAL TECHNOLOGIES AS DATA COLLECTION TOOLS

2.1 The move to digital methods in data collection

Even before the Covid-19 pandemic, digital data collection methods were in development. Surveys were often administered online, with participants clicking on an emailed link to access survey questions on platforms such as Qualtrics, Survey Monkey, and Google forms, which in some cases could also perform basic data analysis. Video conferencing on a multitude of platforms such as WhatsApp, Skype, or (since the pandemic) Zoom allowed researchers to conduct interviews, either with individuals or with groups of people who do not need to share a location. Data processing also made use of digital tools. Software, either as part of or separate from the video- or audioconferencing tools, allows researchers to turn spoken interviews into text for analysis. Such features have revolutionized the laborious transcription process, which only recently had to be conducted by specialists. Even virtual-reality technology allowed researchers to present context-specific probes that allow researchers to formulate questions and lead discussions (Kostakos et al. 2019).

While camera and video recordings have provided additional sources of qualitative data, this has also led to ethical questions. Surveillance cameras have become more common in many societies, and their use as a data collection tool presents legitimate privacy concerns. Despite this, researchers seeking data about spatio-temporal changes in public space usage continue to use cameras as a data collection tool (Whyte 1980; Pink 2007).

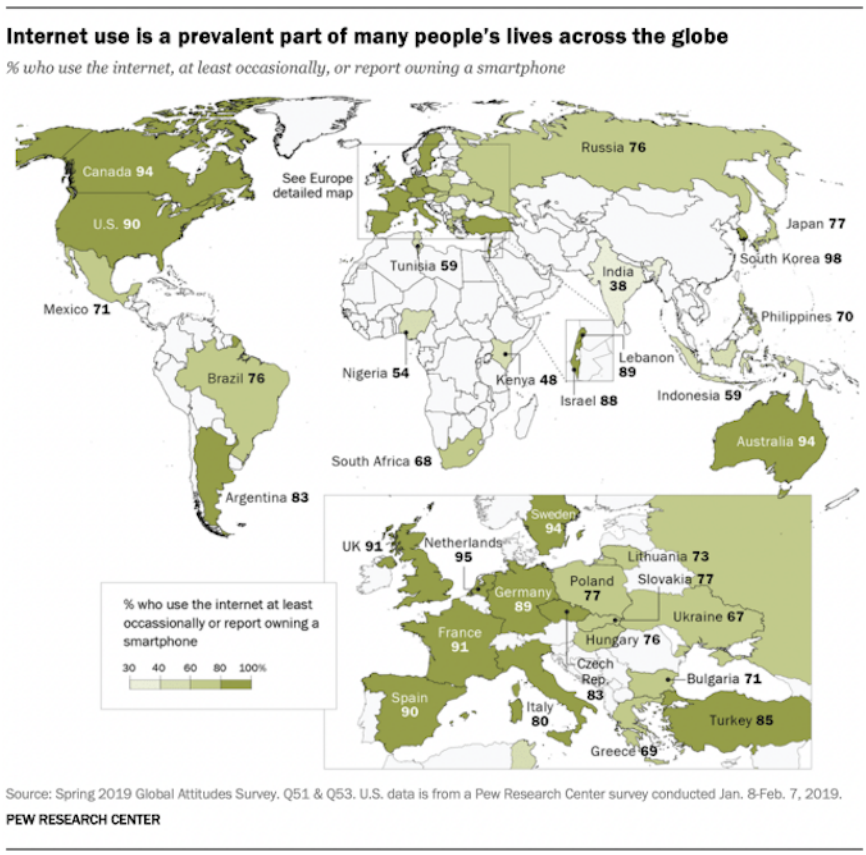


Figure 2: Internet penetration rates by country, 2019. Source: (Pew Research Center 2019)

2.2 Covid-19 research challenges: representation and building trust

The increased reliance on remote data collection during the Covid-19 pandemic brought to light several research challenges, both practical and ethical. One such challenge was finding representative groups of research participants. While this problem is not new, uneven digital access increased its scope, as researchers had to find ways to conduct research with participants who had little or no internet access. Researchers using ethnographic methods also worried about building trust and rapport with potential research participants (Kroese et al. 2021). Researchers working remotely with minority and other vulnerable populations paid special attention to building trust and motivating potential participants to take part in studies.

Representation remains one of the largest challenges in using digital technologies, especially when working in low-income contexts. The use of remote data collection tools to engage with a population of interest is contingent on that population's access, financial capacity, and knowledge of the technology. A lack of access to reliable internet and tools such as mobile phones or computer devices thus severely limits data collection (Kroese et al. 2021). On a global scale, citizens of countries with great power and income disparities, including many low-income countries, frequently do not have universal access to the internet, making digitally based data collection difficult. Figure 2 illustrates the problem: As of 2019, less than half of the population of India had access to the internet, while many African countries had virtually no access (Pew Research Center 2019).

The lack of digital access experienced by many vulnerable populations can ultimately affect a study's inclusivity and predictive accuracy (Kroese et al. 2021). When some participant groups are harder to reach, there is a risk of selection bias in data collection, a bias that can affect study outcomes. As researchers increasingly rely on digital data collection methods, the problem of collecting representative data from communities without universal internet access will have to be considered.

3.0 DIGITAL RESEARCH TOOLS: A SURVEY OF EMERGING METHODS

Digital surveillance and analysis methods have become more sophisticated in the past decades, allowing many data collection tools to incorporate digital technologies. While it is beyond the scope of this paper to calculate how much the Covid-19 pandemic might have further accelerated a move to digital data collection tools, it is not unreasonable to suggest that the pandemic and its lockdowns did encourage researchers to develop more sophisticated digital options as a replacement for in-person data collection. In the next section, we review and assess several digital methods that have emerged or been increasingly adapted since the Covid-19 pandemic.

3.1 Interviewing remotely

Remote interviewing methods have become more frequent since the onset of the Covid-19 pandemic. Countering the findings of some earlier studies, Keen et al. (2022) note demonstrated advantages, such as better access to some marginalized communities, in part due to being able to conduct focus groups where participants can be united without having to travel to a shared physical space. This is advantageous for participants with restricted mobility, or where travel to a research location is difficult for any number of reasons, such as a lack of transportation. Keen et al. (2022) argue that far from being a simple coping strategy during a time of crisis, virtual qualitative research has become an emergent method in its own right, with advantages and disadvantages that are yet to be fully explored.

Part of the development towards remote interviews is arguably due to technological advances in general. Whereas a generation ago, synchronous remote contacts were largely conducted via telephone, the ubiquity of personal computers and smart phones in many parts of the world have made video calls an everyday phenomenon for many. Researchers have found that video interviewing platforms such as Zoom can emulate natural conversation and thus help researchers establish rapport with their interview partners (Archibald et al. 2019).

An example is a study by Roberts et al., (2021) who worked during the pandemic with homeless K-12 students in Houston affected by Hurricane Harvey (which hit Texas in 2017). The researchers initially planned to conduct in-person interviews with school personnel, community service providers, and affected families. This changed, as Covid-19 exacerbated the health and wellness problems of already vulnerable families, while drastically changing schooling experiences and making in-person interviews impossible to conduct. The researchers quickly realized that their participants' post-Harvey experiences had been fundamentally altered through the added impact of Covid-19, calling for a new research focus.

Roberts et al. (2021) thus turned to technology that would allow them to work remotely, researching several options. A literature review established that videoconferencing did allow researchers to establish rapport with their interview partners, and that technical problems such as dropped calls could even increase the bond between researcher and participants as they worked together to solve the problem. Roberts et al. found that the literature reported privacy and other ethical considerations to be similar in virtual and in-person research, and that virtual methods could even be superior, as participants could, for example, use virtual backgrounds to control the researcher's visual access to participants' homes (Roberts et al. 2021).

In their own study, Roberts et al. found recruiting participants affected by homelessness especially challenging. Their original study plan had called for recruiting families through physically visiting area homeless shelters to get to know the staff, who would then serve as a conduit to homeless families. With the pandemic, the researchers had to approach shelter staff through virtual events, while using analog means, such as flyers and posters put up in the shelters, to recruit participants. Working with shelter staff allowed the researchers to bring in necessary technology for interviews, such as computers with internet access, cameras, and microphones. This technology, which became especially important for serving vulnerable populations during the pandemic, also allowed the researchers to

conduct their interviews with participants served by the shelters. In this way, the researchers were able to address problems of the “digital divide”, where low-income study participants do not have access to technology that would allow them to participate in studies remotely.

The researchers did note that recruiting or even reaching potential participants who did not live in a homeless shelter with adequate technology would affect how representative the study would ultimately be. As the researchers put it, “[W]e still had to grapple with equity concerns over whose voices would be captured in our research,” (Roberts et al. 2021).

3.2 Digital-native methods

Digital native methods are methods that do not have an analog version, such as research with online social media accounts or other material that is located online. In a crowdsourced document provided on the internet and revised in July 2021, sociologist Deborah Lupton (2021) collected researchers’ experiences with “Doing Fieldwork in a Pandemic.” Lupton’s list began with methods, such as videoconferencing, that were well established before the Covid-19 pandemic before turning to digital native research methods.

Many methods discussed involved the use of smartphones. For example, in a version of self-ethnography, study participants were asked to use their smartphone’s camera and voice recording features to provide visual or auditory data in response to real-time prompts issued by the researchers. A further version of this method involved participants keeping diaries or journals, with either written, drawn, or photo-based entries that could be sent to the researchers. If the diaries or journals were kept online, using the internet to transfer data to the researchers became straightforward, although larger document sizes (common for graphic data) did require a more robust internet connection.

In some cases, participants were described taking on roles the researchers had previously played. For example, in researcher-led re-enactment videos, researchers document people’s activities by filming them as they go about their everyday lives (often combined with interviews). During the pandemic, researchers reported asking participants to do the filming, either with their phones or with a wearable video camera, such as a GoPro (Figure 3). Shifting camera control to the participants also allowed researchers to conduct “walk along” or “ride along” interviews remotely. Previously, researchers had accompanied participants on such excursions in person.



Figure 3: “Go-along” ethnographic methods have shifted to using cameras participants control. Source: (Anastasia Zhukova 2024)

Several emerging “digital native” methods were discussed in the list compiled by Lupton (2021). Online discussion platforms, some of which have been developed by marketing research firms, allow researchers to upload their questions for participants to answer. Both researchers and additional participants can, with appropriate settings, see and respond to the answers typed by respondents in real time. This method, which combines survey methods with those typically used in one-on-one interviews or focus group interviews, takes advantage of the fluidity of online work to allow researchers to follow up on findings in real time.

In some cases, existing social media apps, such as Facebook Groups, were used to provide a discussion or other activity platform for the researcher and participants. The online and decentralized nature of such groups allows people who might have difficulties engaging in analog group activities due to mobility impairment, time constraints (for example, due to being responsible for young children or infirm family members), or lack of access to transportation to take part in a study. Researchers reported that group activities and study content were often similar to studies using in-person meetings. Respondents reported the online group meetings as more convenient than in-person meetings.

A further form of digital data collection involved using computational analysis, for example through using locational traces in online media or through analyzing material readily available on the internet, such as YouTube and other online videos. This type of research, which extracts data from existing material (even human-based material), is different from working with study participants, since the YouTube archive material does not need to be "recruited" and ethical constraints – including in many cases the need for IRB approval – are minimized (although not erased). With an ever-increasing amount of video material available on the internet, opportunities to make use of such data sources will certainly increase.

Relying on online material such as social media apps can exacerbate the problem with representation, since only data that is already online can be captured. One alternative is to use more conventional analog methods to recruit research participants. Participants can then be provided equipment for collecting digital data.

A fairly inexpensive method of collecting visual data from study participants with little or no internet access is to give them single-use cameras and ask them to use techniques of self-representation (self-portraiture and auto-ethnography) to collect data for the researcher. Although this requires the researcher to recruit and have at least indirect contact with the participant, no internet connection or digital equipment is required by the participant. An example is Anthony Luvera's 2020 photo exhibition about homelessness, an ongoing and collaborative project that is perhaps less scholarly than activist research (Warner 2020).

CONCLUSION

Although digital research methods have been part of the qualitative research arsenal for several decades, the Covid-19 pandemic accelerated their development and use. Increased use of videoconferencing platforms for everyday communication during the pandemic meant that both researchers and their study participants became more familiar with and at ease with their use. Firms providing commonly used videoconferencing platforms developed new features, such as multi-user interfaces and advanced transcription services. Such features are typically more cost-effective than analog methods, thus helping researchers advance their work. Anecdotal evidence in the literature indicated that researchers had no more problems establishing rapport with participants than they had with in-person interview methods, and videoconferencing tools became a ubiquitous tool for carrying out qualitative research that had previously been done in person.

In some cases, researchers had participants take on roles they had once adopted. Participants became videographers where researchers had once held the camera, wrote journal entries, or made photos where researchers had once recorded activities. Arguably, this process gives participants more agency over the direction of the research. Even the control functions of many videoconferencing apps allow participants some say over what researchers can visually and acoustically access. More studies are needed to determine how increased participant agency affects the information participants are willing to share, and what kind of data researchers can thus access and process.

With the Covid-19 pandemic, researchers increasingly turned to "digital native" research methods, expanding the ways in which research can be conducted. Mining existing apps, such as social media or video-sharing platforms, became a further research tool. In some cases, researchers used such apps with participants they had recruited, while in other cases, researchers mined existing data from the apps themselves.

Digitalization, indiscriminately used, can have its downsides. While digital tools became a technical response to pandemic-era research challenges, the Covid-19 pandemic exacerbated social inequities across much of the world and highlighted the need to better understand the lives of vulnerable populations. Some researchers focused on how to give voice to people who are underrepresented in qualitative research, such as the homeless and other marginalized communities who do not have ready access to smartphones or the internet. Although researchers used creative means to gain access to such communities – including working with intermediaries, such as staff at social services centers, working with online platforms to better reach those with a lack of time or mobility, or switching to technologies that do not require the internet, such as single-use cameras – it is clear that more work must be done to develop research methods that will reach the most vulnerable among us.

In assessing digital research methods, the advantages of being able to access study participants with mobility or time challenges must be weighed against the disadvantages of not being able to access populations lacking internet access. More work on these questions is needed. On a global level, the shift to digital research methods must still account for research demands in countries with poor internet saturation, such as India or much of the African continent.

The Covid-19 pandemic accelerated both the race to develop remote research capacities and an awareness of the social limitations of such methods. Further work on emerging methods will help us better manage these social challenges. The emergent methods developed through the constraints of the pandemic are a good foundation for this work.

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The Secondary School Classroom: An Architectural Object to Rethink for Better Support of Educational Success in Quebec. A Literature Review

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ABSTRACT: This literature review explores the impact of classroom architecture on the educational success of secondary school students. It forms part of the work of the Schola research consortium, which aims to guide the renovation of Quebec's public primary and secondary schools. A key premise of this review is that the insights gained can inform the renovation strategies for Quebec's public schools, as outlined in the Quebec Ministry of Education's recent Educational Success Policy, which focuses on supporting students' health, well-being, and academic perseverance. With the majority of Quebec's public schools having reached the end of their first architectural life cycle, renovations are now underway. The method used for this review is based on extensive documentary research conducted across six distinct databases. This approach led to the identification of 16 relevant articles, including six literature reviews and ten field studies, employing both quantitative and qualitative methods. The findings reveal that factors such as the physical environment of the classroom, its layout, and the available furniture and equipment, have a significant impact on academic success, student perseverance, motivation, and well-being. The analysis of these elements highlights the specific requirements for the reconfiguration of classroom spaces, the renewal of furniture, and the modernization of equipment, all of which are crucial for enriching students' learning experiences.

KEYWORDS: Physical environment, secondary school, classroom, adolescent, well-being, educational success

INTRODUCTION

This literature review explores the impact of the physical dimensions of the classroom on the educational success of secondary school students, focusing on their academic performance, health and well-being, as well as their motivation and engagement in learning (MEES 2018). It is part of the work of the Schola research consortium, whose mission includes the launch of an expertise platform in 2024 to guide the renovation of Quebec's public primary and secondary schools. As most public schools in Quebec approach the end of their first architectural life cycle, renovations are currently underway. One of the main challenges is transforming the learning spaces in these schools to better meet the evolving needs of the educational environment and the expectations of new generations of students. Specifically, this review aims to identify the mediating effect of the classroom's physical dimensions on various student behaviors that, in turn, contribute to their educational success. It examines the learning environment from physical, pedagogical, and social perspectives to better understand the complexity of its impact. Additionally, it identifies factors that can inform the requalification of these spaces, the rejuvenation of furniture, and the modernization of equipment to better support learning, new pedagogical approaches, digital technologies, and, ultimately, academic success, perseverance, motivation, and student well-being.

1.0 METHODOLOGY OF THE DOCUMENTARY RESEARCH

For the purposes of this literature review, the physical environment of the classroom is defined as an indoor learning space with or without windows, used for regular teaching, excluding laboratories. This definition includes technological and digital equipment, as well as a variety of semi-fixed or mobile furniture.

The concept plan developed for the literature search included keywords such as "classroom," "secondary school," "adolescent," "engagement," and "well-being," which were further broken down into synonyms and related terms. Initially, 375 titles were identified (Figure 1). Keyword combinations were applied across five databases: two focused on education, Education Source EBSCO (42) and ERIC (152); one in psychology, PsychINFO (23); and two more generalist databases in architecture, Academic Search Premier (46) and Web of Science (40). Additionally, the OECD iLibrary site (20), titles from the bibliography of selected articles, and the document bank of the Schola research group (52) were included. The selected publications consisted of scientific articles published in peer-reviewed journals, written in either French or English. After reviewing the titles and keywords, the list was narrowed down from 375 to 68. A further review of the abstracts reduced the number to 38, and after full-text reading, 16 titles were deemed relevant. These included 10 original studies and six literature reviews. The 10 studies surveyed: (1) were conducted in a secondary school or its equivalent in other countries (such as college or lyceum), (2) focused on students aged 12 to 15 years in good health, (3) considered the physical environment of the classroom, and (4) reported on student behaviors influenced by the dimensions of this environment. Studies that focused solely on common areas of schools were excluded, as were those involving populations of young people with

overweight/obesity, disabilities, or learning difficulties. Both quantitative, qualitative, and mixed methodologies were considered.

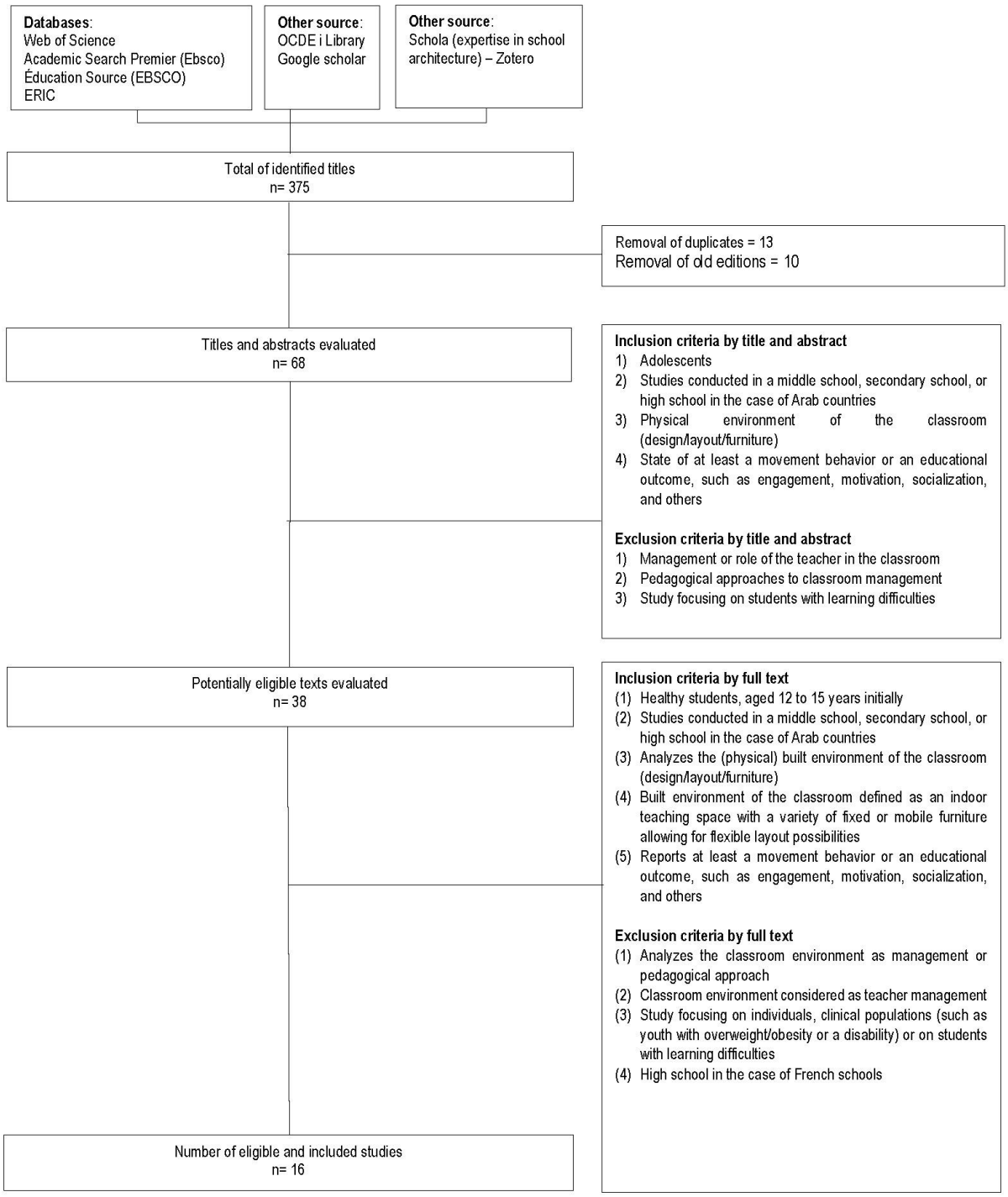


Figure 1: Research protocol and resulting corpus. Source: (Ballita 2023)

2.0 PRESENTATION OF THE CORPUS OF REVIEWED TEXTS

A comparative matrix was used for the systematic analysis of the six literature reviews and 10 empirical studies identified. The analysis was based on the following criteria: (1) the author(s) and their field(s) of research, (2) the year of the study, (3) the location of the study, (4) the methodology, (5) the type of analysis, (6) the sample size and participant profile, (7) the physical characteristics of the classrooms studied, and (8) the main findings.

Although no specific publication date limit was set, all 16 articles were published after the year 2000, with 14 published between 2010 and 2021. Psychology and educational sciences dominate these studies, with the majority authored by researchers in these fields (11/16), including three solely from psychology and three from education. Two publications were authored solely by researchers in architecture, while only three articles combined expertise in architecture, education, and health. Four of the six literature reviews cover both primary and secondary schools,

encompassing 88 articles published between 1978 and 2013. The remaining two reviews focus exclusively on secondary schools, identifying 27 studies published between 1960 and 2019. The 10 empirical studies were conducted across several continents: four in Australia, three in the United States, and two in Europe (one each in Scotland and England). One study was conducted in multiple countries, including the Netherlands, Norway, Japan, Singapore, China, and India. All the countries involved have aging school infrastructure, with some studies focusing on recent renovations or newly constructed schools. Four of the empirical studies employed qualitative methods: two based on direct observations, one using participatory activities and conceptual mappings, and the last involving interviews with teachers and focus groups with adolescents. Two quantitative studies examined various school buildings, classroom layouts, and furniture arrangements: one focused on the buildings of nine secondary schools, and the other on three types of classrooms within the same secondary school. Lastly, four studies utilized a mixed-methods approach, combining focus groups, interviews, observations, and plan analysis. One of these studies analyzed the plans of 59 secondary schools across multiple countries.

Table 1: Comparative matrix of the 16 reviewed texts. Source: (Ballita 2023)

Author	Authors' field	Year	Type of research	Method adopted	Country	Sample	**School level**
Bluyssen		2017	Literature Review	Documentary research	N/A	N/A	Primary and secondary
Byers et al.	Education, psychology	2018	Qualitative study (quasi-experimental)	Comparative analysis of 22 classrooms + Survey on student attitudes	Australia	3 buildings built between the 1940s and 1960s, 22 classrooms	Secondary
Byers et al.	Education, psychology	2018	Literature Review	Documentary research in 12 databases	N/A	21 articles in this journal, ranging from 1960 to 2016 (comparative or quasi-experimental studies)	Secondary
Cheryan et al.	Psychology	2014	Review of the literature	Documentary research	N/A	48 scientific articles, from 1978 to 2014	Primary and secondary
Dovey et al.	Architecture	2014	Qualitative and quantitative study	Plan analysis"	Japan, Singapore, the Netherlands, China, India, and Norway	An international sample of 59 schools focusing on the English-speaking world	Primary and secondary
Edgerton et al.	Psychology	2011	Qualitative and quantitative study	6 focus groups + 1 questionnaire Survey + 3 groups of students	Scotland – United Kingdom	7 to 11 participants per group, total sample of 51 students from levels S1, S3, and S5	Secondary
Fouad	Architecture	2017	Quantitative study	Comparative case study	England – United Kingdom	9 secondary schools	Secondaire
Fredricks et al.	Psychology	2004	Literature Review	Documentary research	N/A	N/A	Primary and secondary
Gislason	Education	2010	Qualitative and quantitative study	Behavioral observation and semi-structured interview	Minnesota – United States	3 secondary schools, 11 teachers, and 15 students	Secondary
Guardino et al.	Education	2010	Qualitative study (quasi-experimental)	Concept map	N/A	Concept map with students aged 12-15 years	Primary and secondary
Hidding et al.	Public health	2018	Qualitative study	Focus group + observation	N/A	Students aged 12, 14, and 16 years	Secondary
Imms et al.	Education	2017	Quantitative study	Comparative quasi-experimental case study	Australia	3 classroom modes, occupied by 3, 7th-grade classes, receiving a similar curriculum while retaining the same teacher throughout each intervention	Secondary
Kariippanon et al.	Education, psychology	2017	Quantitative study	Qualitative case study approach	Australia	Teachers (interview with 35 participants), students (6 focus groups consisting of 5 to 6 students)	Primary and secondary
Kariippanon et al.	Education, psychology	2021	Literature Review	Documentary research	N/A	5 quantitative articles and one qualitative article were selected, ranging from 2014 to 2019	Secondary
Ryan	Education psychology	2001	Qualitative study	Qualitative case study approach	N/A	Targeted students: 11-16 years old	Secondary
Ucci et al.	Architecture, éducation	2015	Literature Review	Documentary research	Australia	20 were included in this review, ranging from 2008 to 2013	Primary and secondary

3.0 RESULTS

The results of three studies show that the learning capacity and academic performance of young people are most often associated with the physical environment in which their learning takes place (Bluyssen 2017; Byers et al. 2018; Cheryan et al. 2014; de Dear et al. 2015). One literature review also reports that the design of learning spaces can impact student motivation (Ucci et al. 2015).

Several authors agree that, given the number of years students spend in school, the physical environment of the classroom significantly influences their life experiences, behaviors, and social relationships (Bluyssen 2017; Cheryan et al. 2014; Eccles & Roeser 2011; Germanos 2009; Jodelet 2015; Mazalto & Paltrinieri 2013). According to some studies, classroom design can foster aggressive behaviors (Bluyssen 2017; Gislason 2010; Kritchevsky et al. 1969), reduce student participation, and disengage students from their learning (Byers et al. 2018; Gislason 2010; Mahat et al. 2016; Dornfeld 2016; Ucci et al. 2015). Conversely, a classroom environment adapted to students' needs encourages participation and reduces aggressive and distracting behaviors. Architectural characteristics and symbolic features of classrooms can either hinder or facilitate student performance and academic perseverance in secondary schools (Bluyssen 2017; Cheryan et al. 2014; Edgerton et al. 2011; Gislason 2010; Ucci et al. 2015; Winterbottom & Wilkins 2009). Providing students with a classroom where they feel at home and comfortable, whether alone or in groups, allows them to establish a sense of recognition and identification, which in turn positively influences their well-being (Bluyssen 2017; Fredricks et al. 2004), sense of control (Edgerton et al. 2011; Laquerre 2018), and social relationships (Bluyssen 2017; Edgerton et al., 2011).The following sections specifically address the dimensions of the physical environment of classrooms that impact aspects of educational success. The identified evidence is classified into four physical dimensions of the classroom: 1) size and configuration of the space, 2) physical ambiance, 3) furniture and displays, and 4) technology. These categories are cross-referenced with three dimensions of educational success: 1) perseverance and academic success, 2) health and well-being of students, and 3) behaviors likely to contribute to these (Table 2). The next section reviews these categories one by one to present the identified evidence (Table 3).

Table 2: Table showing the relationship between the three categories of classroom architecture and adolescent behaviors. Source: (Ballita 2023)

	Architecture (Classroom scale)																	
	Physical Ambiances								**Size, configuration**					**Furniture**				**Digital**
Behavior / perception (adolescent)	Lighting	Air quality	Thermal	Acoustics	olfactory	Visual appearance	Physical quality	Color	Size	Spatial typology	Shape	Spatial density	Accessibility	Furniture arrangement	Variety of furniture	Object	Display	Equipment/ technology
Academic success	●	●	●	●	●	●	●				●	●		●	●			
Attendance		●					●											
Long-term success	●		●						●	●		●					●	
Learning ability	●		●	●	●	●	●				●		●	●	●	●		●
Creativity	●		●	●		●											●	
Physical health	●		●	●		●	●							●				●
Psychological health	●			●	●	●							●		●	●	●	●
Well-being	●	●	●	●		●	●		●		●		●	●	●			●
Physical comfort	●	●	●	●		●	●		●	●	●	●		●	●	●	●	
Visual comfort	●					●	●	●									●	
Stress	●		●	●	●	●	●					●	●		●	●		
Interaction	●		●	●			●	●						●			●	
Socialization					●						●		●					
Autonomy							●	●	●	●		●						●
Engagement	●		●	●	●	●	●	●	●				●	●	●	●	●	●
Concentration				●	●			●			●		●					●
Motivation	●		●		●	●	●				●			●		●	●	●
Sense of belonging					●	●	●						●				●	●
Sense of pride						●	●										●	
Sense of security	●			●	●		●		●	●	●				●	●		
Attitudes	●		●	●	●	●			●		●	●		●				
Joy of learning		●				●												
Self-regulation	●		●	●	●					●								

Table 3: Table showing the relationship between the three categories of classroom architecture and adolescent behaviors. Source: (Ballita 2023)

| | | Classroom scale | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Behavior/perception (adolescents) | | | | | | | | | | | | | | | | | | |

classrooms perform better than those with less natural light exposure (Bluyssen 2017; Imms & Byers 2017; Kariippanon et al. 2017; Ucci et al. 2015). Bluyssen's (2017) literature review, although considering both primary and secondary school students, highlights the influence of acoustics on communication abilities, attention, and memory, which can negatively impact motivation and achievement levels. According to Cheryan et al. (2014), acoustic vibrations from both internal and external sources in classrooms contribute to discomfort and stress. Several studies show that poor acoustic quality in classrooms, caused by noise from heating and ventilation units (U.S. Architectural Transportation Barriers Compliance Board 2002, cited in Cheryan et al. 2014), airplane flight paths (Evans & Maxwell 1997, cited in Cheryan et al. 2014), and road traffic (Bluyssen 2017), is linked to students' well-being and comfort (Bluyssen 2017; Gislason 2010; Ucci et al. 2015). Research by Lupien (2009, cited by Guardino & Fullerton 2010) suggests that students' perceived loss of control over noise nuisances is a psychological determinant of stress, with significant implications for individual well-being and mental health.

Conversely, good air quality has a positive effect on students' health and academic performance (Bluyssen 2017; Chatzidiakou et al. 2012; Gislason 2010; Ucci et al. 2015). Studies by Bluyssen (2017) and Gislason (2010) associate air quality (e.g., CO2 levels, air renewal rate, humidity) with comfort, health, and well-being in students. Research conducted in Australia has demonstrated the influence of the thermal environment in classrooms on student comfort, well-being, and academic performance (Bluyssen 2017). Additionally, three experimental studies suggest that male adolescents are more sensitive to temperature changes compared to their female counterparts (Allen & Fischer, 1978, cited by Cheryan et al. 2014; Burgeson 2017; Carignan 2018, cited by Cheryan et al. 2014; Kariippanon et al. 2017).

3.3. The furniture and displays

Furniture encompasses all furnishings in a classroom, such as desks, chairs, and tables. A display is a generic medium typically associated with educational material (Kariippanon et al. 2017) but can also serve as a tool for personalization; it is considered an integral part of classroom organization. According to Byers et al. (2018), the spatial arrangement of a classroom influences students' attitudes toward their learning experiences and their engagement.

Some studies suggest that offering a variety of furniture and displays can promote student autonomy by enabling them to work individually or in groups (Kariippanon et al. 2017). Providing diverse workspaces and furniture options allows students to make their own choices, reinforcing their sense of control (Cheryan et al. 2014; Kariippanon et al. 2017). Byers et al. (2018), in their study of 22 classrooms across three secondary schools in Australia, and the review by Ucci et al. (2015), found that the arrangement of school spaces and the variety of furniture affect both the level of physical activity and the seating position of students. A diverse range of furniture, when well-organized, contributes to effective class management and high student engagement (Cheryan et al. 2014). The arrangement and variety of furniture also facilitate the teacher's work and promote quiet, individualized student activities (Legout 2018, cited by Kariippanon et al. 2017). However, some studies report that a variety of furniture can lead to agitation and anxiety among secondary school students (Ucci et al. 2015). This variety also impacts students' comfort and their degree of interaction with both peers and teachers (Cheryan et al. 2014; Kariippanon et al. 2017; Ucci et al. 2015).

Several studies and scientific reviews suggest that learning environments with a variety of furniture options, arrangements, and resources are beneficial for teaching, learning, and the social, emotional, and physical well-being of students (Cheryan et al. 2014; Kariippanon et al. 2017; Ucci et al. 2015). However, some studies indicate that incorporating furniture elements such as stools encourages greater mobility and reduces the time spent in a seated position, which may cause discomfort among students (Kariippanon et al. 2017) and negatively impact learning and engagement (Imms & Byers 2017).

3.4. Digital equipment

Digital equipment in the classroom, including computers, projectors, tablets, and interactive whiteboards, contributes to innovative learning environments where teaching is supported by digital tools. Cloutier, Denault, and Drapeau (2019), experts in psychoeducation, secondary education, and youth psychology, suggest that adolescents' motivation in learning spaces is influenced by the digital environments they encounter during their transition from childhood to adulthood. A quasi-experimental study indicates that a more dynamic and flexible space, where technology is actively integrated, improves classroom outcomes (Imms & Byers, 2017). In these environments, students feel more comfortable, reporting a greater sense of well-being (Imms & Byers, 2017).

The availability of diverse choices for engaging with learning materials also supports students' self-regulation (Cheryan et al., 2014; Kariippanon et al., 2017). According to a literature review by Byers, Mahat, et al. (2018, p. 174), learning spaces equipped with digital and visual technologies significantly influence learning, motivation, and student engagement. Digital resources in the classroom promote autonomy, allowing students to work individually or in groups, and enabling them to access both digital and traditional resources at various points during a lesson, depending on the task and their progress pace (Kariippanon et al., 2017). In a study by Byers et al. (2018) across 22 classrooms in Australia, all classes in innovative learning environments rated their motivational expectations and values higher compared to traditional classrooms. Multiple studies suggest that students in these tech-enhanced environments report greater cognitive and emotional engagement than their peers in conventional settings (Byers, Imms, et al., 2018; Imms & Byers, 2017; Kariippanon et al., 2017). Furthermore, Imms et al. (2017), in a study involving 7th graders in three types of classrooms in Australia, found that more dynamic and adaptable spaces, enhanced by technology, significantly improved students' perceptions of their learning experience.

But what about older schools that lack such technology? How can we stimulate the interest of young people in these environments?

4.0 DISCUSSION

This review primarily aims to understand the influence of classroom architecture on the well-being, engagement, and motivation of high school adolescents. The fact that many countries from which these studies originate have aging school infrastructure, with most schools built following the educational reforms of the 1960s, in addition to the growing need for school renovations, helps explain the emergence of these studies. Most research focuses on schools that are either due for renovation or have already undergone renovations, with fewer studies addressing the design of new schools. The establishment of the Programme for International Student Assessment (PISA) by the OECD (Organisation for Economic Co-operation and Development) in 2000, which includes the countries involved in this study, has undoubtedly had a significant impact on the field. Indeed, many of the selected articles reference this program. Similarly, the countries involved in these studies have also carried out school reforms or established educational success policies in the 21st century, much like Quebec.

The physical environment of classrooms is categorized into three aspects: physical ambiance, size/configuration, and furniture/technology. These categories are highlighted based on the analyzed studies, though it is clear that they have been studied unevenly. While physical ambiance and classroom layout have been extensively explored in relation to educational success and engagement, the arrangement and variety of furniture and displays have received less attention (Table 2). Furthermore, while all three categories - physical ambiance, furniture/displays, and size/configuration - are often linked to students' academic perseverance, fewer studies examine the relationship between these three aspects and mediators of educational success among adolescents, suggesting areas for future research.

Preliminary observations conducted in six schools pointed to external factors that influence the internal functioning of classrooms, such as variations in room allocation for different subjects, student groups, and teachers. These dynamics differ significantly across countries and preceded the current literature review. Notably, the studies examined here do not focus on hallways and informal spaces, which are common in many schools in Quebec. Although several studies acknowledge the role of hallways and informal spaces in influencing the classroom climate and overall environment—often characterized by noise—none offer a detailed description of these areas. While there is an understanding of how the built environment of a classroom impacts adolescents, few studies explore how activities unfold in classrooms during successive class sessions. Concepts such as adolescent happiness, autonomy, self-esteem, and socialization take center stage in the studies, yet factors like a sense of belonging, pride, appreciation, concentration, interaction, self-perception, enjoyment of learning, and long-term success remain largely unexplored. Additionally, the role of relaxation, breaks, and transitions between classes is barely addressed. Issues related to mental and physical health, psychological stress, and anxiety, though present in schools, are not frequently linked to classroom environments. Regarding classroom characteristics, ambient quality, layout, and digital equipment are often studied in connection with academic performance and adolescent comfort but are generally viewed as criteria for satisfaction and motivation that are rarely described in detail. Terms like decoration, displays, aesthetics, and atmosphere remain ill-defined in the studies, while physical ambiance and layout are more explicitly covered (Table 2). The dimensions of joy, happiness, well-being, and adolescents' perceptions are among the least explored classroom characteristics. These dimensions are undoubtedly important to study, as they are key to supporting the well-being, motivation, engagement, and academic perseverance of young people in their educational journey.

CONCLUSION

The analysis of physical environments, diverse arrangements, and furniture from the reviewed studies provides valuable insights into the factors influencing educational success, students' use of classrooms, and the characteristics of learning spaces. These elements reveal students' behaviors and emotions during learning sessions. While most studies emphasize the importance of the physical environment for student well-being and performance, they often overlook aspects such as health, happiness, and motivation, and are less systematic in analyzing classroom environments and school plans.

The next phase of this research, focusing on developing a tool for secondary school classroom design and renovation, is crucial. It will involve data collection in four schools in Quebec through direct observations, furniture inventories, teacher surveys, and interactive activities with students. Built on established criteria, this phase aims to create precise classroom designs based on student perceptions to enhance their well-being and educational success, aligning with the policies of the Quebec Ministry of Education.At the same time, ensuring optimal learning environments requires addressing the minimum structural quality of classrooms, particularly in older schools lacking digital equipment, especially in light of the challenges posed by the surge in online learning during the pandemic.

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Investigating The Narrative Space through Reader-Viewer Experience in Film “Roma”

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ABSTRACT: The aim of this study is to analyze the spatial connections within narrative space and gain insights into the perceptual and experiential processes of individuals in the context of architectural space as portrayed in the written word (movie scripts) and movie representations. The transformation of the subject's experience occurs while transitioning between textual and visual forms of space, due to inherent distinctions between the two mediums. The comprehension of the subject's encounter inside the realms of textual and cinematic domains facilitates the establishment of connections among the diverse narrative spaces.

The film "Roma" was chosen as a pilot study for this aim because of its rich spatial representations in both mediums and since it was written and directed by the same artist, Alfonso Quaron, avoiding multi-layered interpretation processes. The investigation of the house, which serves as the film's main backdrop, is carried out via protocol analysis. Within the framework of protocol analysis, a two-stage technique is implemented: conducting interviews and assessing participants' mental sketches. The data were categorized based on thematic groupings, which are created according to theoretical background, in the AI-based Atlas.ti software, a tool designed for qualitative data analysis. The present study involves a focus group including 13 students from the department of architecture. Through a preliminary investigation, the current study examines the reproduction process of various representations of the narrative space inside the perceptual layer of the subject's spatial perception. In prospective research endeavors, it is expected that the investigation will be conducted on a broader scale by expanding the participant group. This study can be carried forward with the question of how imagination and remembering are constructed in the process of spatial reading through literary and cinematic narrative. As a result, this study, which focuses on the subject's role and its perceptual-experiential layers, can contribute to future research regarding the understanding and transmission of evolving spatial contexts at the intersection of the physical and abstract realms at the human-scale in the context of architectural education.

KEYWORDS: Narrative space, reader’s experience, viewer’s experience, textual narrative, cinematic narrative

INTRODUCTION

Individuals engage and develop relationships with their living environment. This consistent interaction constructs the new ways for thinking and building of space. In addition to its varied definitions by different theorists, sociologist and philosopher Henri Lefebvre (1991, 33-39) presents a triad of social space and spatial relationships, consisting of perceived, imagined, and lived space. This clearly demonstrates that space encompasses not just the physical realm, but also the conceptual and imaginative aspects. In this regard, space or phenomena transmits stimuli/signals to the subject, which the subject perceives and processes in the context of the human-space relationship. In addition, everyone molds the environment's narrative through their own experiences. aims to scrutinize the changing in the subject's perceptual/experiential processes in literary and cinematic transformations of narrated space.

People's relationships in physical/cartesian space have previously been attempted to be understood using many theories, including people-environment theories and phenomenology. However, it is widely recognized that physical location is not the only space where humans communicate. People experience and construct space in a variety of ways, including through written or visual channels. Understanding people's interactions and experiences in fictitious space is essential given the constantly developing concept of space.

Interaction and relationality in space, which has different expansions from physical to virtual, from center to periphery, also differentiates. When we look at Deleuze's (1987, 474-503) definition of notion of space, we encounter a structure that evolves from a singular and static physicality to “becoming”. Along with the changing notion of the space, the relationship between bodies has also been redefined. The body also has the capacity to perceive through different channels in this formation which implies a change in the notion of the body. With the representation and experience of virtual space, the changing experience structures, the post-human era (Hayles 1999, 16-18) and the affect theories, body and experience are dismantled. Just as space does not have a physically stable meaning, the body and experience also leave their place to different states of the body such as disembodied experience, cyborg body and non-human bodies (Braidotti 2013, 89-102; Haraway 1991, 149-181). Here, instead of talking about a static subject-object relationship, the dynamic interaction of movement and flow with each other is examined. This interaction is explained as "geographies of action" by De Certeau (1984, 91-101), who examines

the experience of narrative. We believe that the current research milieu provides a fertile ground for more research into the evolving perception of bodies across different narrative mediums.

This study focuses on space as written and visualized in different narrative types. Understanding the subject's experience in the literary and cinematic spaces enables the construction of relationships between the various narrative spaces. In this context, the subject's experience in literary and cinematic spaces is chosen to be analyzed through narration and space concepts. Since it examines the subject's experience in narrated space, the study is founded on basic standpoints which are the phenomenological approach (Merleau-Ponty 1945), narrative theory (Genette 1972), literary theory (Caracciolo 2013), reader's response theory (Iser 1978), and cinema theories such as reception theory (Hall 1973).

The main objective of this study is to examine the spatial relationships in narrated spaces and the perceptual and experiential processes in literary and cinematic representations of architectural space. The study comprises the subject's role as a reader and viewer, the subject's perception and experience of literary and cinematic narratives, and spatial perception, interpretation, and representation in literary and cinematic narratives. The pilot study was conducted with a focus group of architecture and design students. Hence, the second objective is to see how students who encounter and design both literary and cinematic narratives in architectural education perceive these representations. Therefore, another objective of the study is to investigate the impact of written and visual narratives on the students' perceptions of architectural education. This pilot study represents the initial phase of the research conducted in this context.

1.0 METHODOLOGY

The pilot study is carried out through literary and cinematic narrative lenses. Thus, it is aimed at examining the perception of space and imagination of architecture students and the processes of [re]interpreting space. Therefore, the participant and case selection were very critical. Architecture students were selected as participants because they are familiar with both the processes of reading and interpreting the narrative of space and the representation of space. Additionally, architecture students have a unique perspective on the physical and conceptual aspects of space due to their training and education. By focusing on this specific group, the pilot study aims to gain valuable insights into how these individuals perceive and make sense of spatial narratives in both literature and film. This targeted approach allows for a more in-depth analysis of the participants' experiences and enhances the overall validity of the research findings.

In the pilot study selection, preliminary script readings were made for four previously selected movies with a director-as-writer approach, and these films were watched. It was ensured that the selected movie had spatial richness in both literary narrative and cinematic narrative. The duration and scope of the pilot study were important limitations in case selection. Considering the importance of the cultural factor in the perception of the movie seen in the literature review, it is thought that the selected movie should have a cultural background that is distant from all participants. Therefore, we could observe the impact of the cultural factor on the perception of the narrative space. Another variable in case selection was the spatiality of the cinematic narrative. We preferred a movie that focuses on a single space, which is a house, instead of containing many spaces. It is thought that the familiarity of "house" to the participants and its emotional and semantic reflections will provide significant discussions in the imagination and reinterpretation processes. In this context, Roma, directed and scripted by Alfonso Quaron in 2018, is chosen for the pilot study.

Roma is a film that takes place primarily within the confines of a house, allowing for a deep exploration of the space and its significance. By choosing a familiar setting like the home, it is believed that participants will be able to relate to and engage with the narrative on a personal level. Additionally, Roma's critically acclaimed storytelling and cinematography make it an ideal choice for studying the perception of both narrative types.

Thirteen architecture students participated in the pilot study, which was designed as a one-day study. The pilot study consisted of reading and sketching exercises in the morning and a movie screening and focus group interview in the afternoon. This study encompasses the students' cognitive and hands-on output.

During the study, we gathered both students' sketching data and verbal interpretations by conducting a cognitive mapping study and a focus group interview. The data were categorized based on thematic groupings, which are created according to theoretical background, in the AI-based Atlas.ti software, a tool designed for qualitative data analysis.

1.1 Defining characteristics of movie narrative

The film takes place in the heart of a home, focusing on the homeowner and housekeeper in the Colonia Roma neighborhood, which was inhabited by the upper middle class in 1970s Mexico City. The narrative of the film revolves around the daily experiences of the housekeeper, Cleo, and effectively portrays the socio-cultural dynamics of the period, as well as the major changes that occur in the daily lives of the characters. The film has autobiographical themes derived from Alfonso Cuaron's childhood memories. The simple depiction of everyday life in both the screenplay and the movie itself, as well as the simple narrative of the settings, has contributed to this movie's selection for the pilot study.

Examining the main characters' use of the home environment is an important component of the film's character-space interaction. Cleo, the housekeeper in the movie, effectively utilizes the spaces and reveals the limitations of certain areas of the house. Sofia and Antonio, the owners, have distinct usage areas throughout the house compared to Cleo. Children, however, recreate these spaces beyond their present purpose through play. Borras, the family's pet, has restricted space usage.

The researchers sequentially and contextually examined the movie and script. First, the script was examined, and the literary spatial narratives that characterized the house setting and occurred within it were identified. Accordingly, the writer provides a general description of the settings at the start of the script and the spaces of the house are depicted in the initial pages of the scenario. As the plot progresses, spaces are presented to the reader within the narrative, going beyond the basic description. Then the movie and its cinematography were examined. Similarly, the first 30 minutes of the movie take the audience on a journey through the house and introduce its spatiality. This condition has been an additional crucial factor in selecting this film for the pilot study. The spatial depiction of the narrative can be seen in Figure 1. The sequential depiction of literary narrative is elaborated on in the next part of the paper.



Figure 1: Spatial depiction of cinematic narrative: Small patio and patio (left above), kitchen (right above), outside of the home (left middle), downstair hall (right middle), upper stair hall (left below), roof (right below). Source: (The movie captured from Roma by Alfonso Quaron (2018, 00:00:00–00:30:00) and image is created by author 2024)

1.2. Sequential depiction of literary narrative

During this phase, the sequences of the spaces in the scenario (referring to the first 30 minutes of the movie shown to the students) are analyzed by authors. The literary narrative centers around Cleo and portrays her daily experiences through the involvement of supporting characters. Therefore, Cleo's daily activities within the house also provide the reader with a sense of physical movement. The literary narrative locations are presented in a sequence of time, along with their corresponding definitions in the scenario in each diagram. The time layer is visually represented using distinct colors. These colors are used to represent various periods throughout the day, and as the plot's date shifts, an additional layer is generated to accommodate new sequences of spaces. Numerical indicators are used in sequential diagrams to represent the starting and ending nodes of the plot, as well as the order of action.

The initial section encompasses the largest number of spatial details inside the scenario. This section begins with the patio and extends an invitation to the reader to explore all spaces within the house, concluding with the maid's quarter (Figure 2). The authors made seven sequential diagrams reflecting the movement of Cleo in the film. Based on the spatial sequence analysis of the literary narrative, the story starts on the patio and concludes on the roof. Both the content analysis of the script and the sequence analysis clearly indicate that the patio is the central location in the literary narrative.

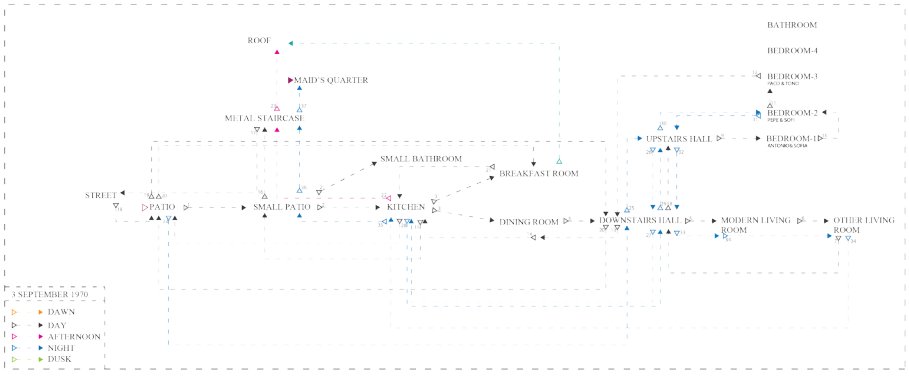


Figure 2: Sequential depiction of the literary narrative (image created based on Roma: The Screenplay by Cuarón, 2018). Source: (Author 2024)

Upon analyzing the textual content, sequence, and visual elements of the literary and cinematic narratives, it became evident that the spaces were described individually in the first four pages of the screenplay, and this description is further supported by the cinematic narrative in the initial 30 minutes. The workshop, which aims to concentrate the students' attention on the home space, is structured in two phases to collect pilot study data. During the initial section, which consisted of two sessions, students analyzed the literary narrative by means of the scenario with sketches. They read the first four pages of the screenplay in the first session, which depict the house, and then a longer edited version prepared by the authors that elaborates on the spatial elements of the house in the screenplay. In the second phase, the movie's first 30 minutes were screened, followed by a focus group interview.

2.0 DATASETS AND METHODS

Students initially read the script's first four pages. After that, a brief 25-minute study on cognitive mapping with the instruction "Illustrate your initial perceptions of the home depicted in the literary narrative" was conducted. In the first session of the sketching study, students expressed their initial perceptions. During the second session, the students read the fully edited script, which depicted the home environment. The objective of the second session was to gain a deeper comprehension of the plot and spatial connections, in contrast to the individual narratives of the spaces in the first session. The students were asked, "How do you envision the domestic environment portrayed in the scenario?" and conducted a 30-minute cognitive mapping study in this session. These sessions helped us to observe how students see distinct settings and their interconnections through a comprehensive narrative.

Students in the cognitive mapping study had the freedom to choose their representation tools and were not imposed on a specific sketching approach. We believe that a wider range of representation tools can enhance the comprehension of the processes of imagination and interpretation. According to Huynh and Doherty's study (2007, p. 288), digital cognitive mapping has more capability to record and analyze data. Yet, this study allowed both techniques (digital and hand-drawn) to see and compare the effects of representation tools for the further phases of this ongoing research.

Seven students utilized the Procreate software to create digital cognitive sketches on iPads. They captured screenshots at regular intervals of five minutes and documented the entire sketching process as a video in a recording. A total of six students utilized the technique of alternating layers every 5 minutes to produce their hand-drawn works on the sketch papers provided throughout the study (Figures 3). Utilizing both digital and hand-drawn cognitive mapping techniques in the pilot study can provide insight into the potential impact of digital sketching and hand drawing on imagination, memory, and reinterpretation processes in further studies.

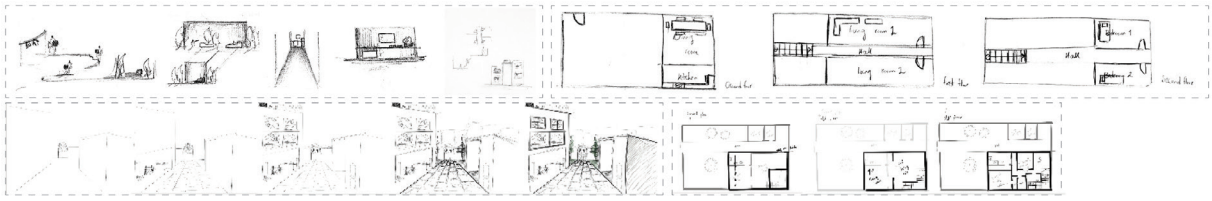


Figure 3. First session of cognitive mapping study example: Participant 7 (hand-drawing) (left above) and 5 (digital drawing) (left below) and second session of cognitive mapping study example: Participant 7 (hand-drawing (right above) and Participant 5 (digital drawing (right below). Source: (Participant 5 and Participant 7 2023. Image is created by author 2024)

The cognitive mappings were analyzed using the Atlas.ti tool. The study's conceptual background outlined encoded visual data based on the concepts and concept groups using this program. In the coding process, the similarities between the visual and verbal data of the participants were considered. The codes and code groups are generated by describing the notions that arose from both the focus group interview and the cognitive mapping study. Unlike the focus group interview, which relied on both literary and cinematic narratives, the cognitive mapping study mainly gathered visual content codes under the category "Subject's Interpretation in Literary Narrative (SILN)".

Following the initial 30 minutes of the film, a focus group interview was conducted with the students who took part in the cognitive mapping study. The primary focus of this 45-minute non-structured interview was their interpretation of the scenario through their drawings and subsequent remarks following the movie screening. In this session, each student's discussion environment has experienced minimal interference. After that, the audio data was transcribed using the Atlas.ti software. Each participant's comments were categorized and coded under the titles "Subject's Interpretation in Literary Narrative (SILN)" and "Subject's Interpretation in Cinematic Narrative (SICN)" for the purpose of conducting relationship analysis. Contrary to the coding scheme used for cognitive mapping on literary narrative data, the focus group interview includes remarks and comparisons related to both the scenario and the movie. As a result, concept groups are classified into two distinct categories.

In summary the collected data is categorized into three scales for the analysis:
- Students’ sketches (cognitive mapping) after reading two rounds of screenplays
- Content analysis of focus group interview focusing on verbal interpretation of literary narrative
- Content analysis of focus group interview focusing on verbal interpretation of cinematic narrative

Analysing reinterpreted spatial narratives allowed us to discern the correlation between the roles of a reader and a spectator in imaginative and perceptual processes.

3.0 FINDINGS

The analysis of cognitive mapping demonstrated a greater quantity and diversity of spatial data. However, all three scales exhibit the presence of characters, atmospheric features, the urban environment, and the differentiation between interior and exterior spaces. Verbal interpretations of literary and cinematic narratives refer to settings in broader terms. Within this study, it is observed that cultural issues appear in the verbal interpretations collected subsequent to the movie screening, more than the cognitive mapping. When analysing the interview data one comes across comments pertaining to the cultural and social environment. For instance, Participant 5 highlights the connection between the staircase and Mexican culture, emphasizing the use of clay and stone tiles to evoke a traditional Spanish aesthetic. Furthermore, students note that these details are not readily apparent through reading alone but rather become evident when watching the movie.

> When I saw the movie, I could see how traditional it is and how unique that specific staircase is to the Mexican culture. You can't really perceive those things when you're just reading, but when you watch the movie, it kind of just gives you the exact context of everything. Participant 5
>
> When she mentions the roof scene, it did pop into my mind like I was watching a documentary where they were talking about the squatters of India, and this cityscape was exactly the same. Participant 6

Participant 6 draws a parallel between the roof scene in the movie and a documentary about squatters in India, suggesting that the cityscape depicted in both scenarios is strikingly similar. Just as culture and prior experiences shape the experience of a physical space, they also influence the audio-visual experience of a movie narrative. Even if Participant 5's comment on the experience of being a reader and spectator is inadequate for a comprehensive argument, it is significant to see how perception changes in different experiences. It is evident that the type of narrative experienced has a profound impact on an individual's imagination and perception.

It is noteworthy that the participants reinterpreted the meaning of the narrative through the visual representation of the space after watching the movie. Participant 6 explains the significance of the portrayal of the roof space in the movie by stating, “Same work, same style, same people doing different works on different roofs.”. Similarly, the same space is described by Participant 7 with the following statement:

> But I think it's reflecting the whole city because of the scenes like the mushrooms, you know, and the laundries and people's clothes. I think it was trying to say that this is like we're showing this life, and it can be applied to the other houses in Mexico as well. Participant 7

On the space-narrative axis, movie narrative goes beyond just audio-visual representation and presents experience through space. Below the findings related with three scales of the study are elaborated in detail.

3.1. Cognitive mapping in literary narrative

The visual depiction of literary narrative categorizes data into character, atmosphere/event, context, spatial definition, spatial representation, and spatial organization. Students' drawings often contain data derived from the spatial definition and spatial organization groups. Accordingly, while all students' drawings include staircase (total frequency: 39), 11 students define spaces with spatial boundary (total frequency: 39). Upon examining how students depict literary narrative spaces, the prominence of perspective drawing (total frequency: 22) and plan drawing (total frequency: 16) is remarkable. In the initial phase of the cognitive mapping study, students depict the spaces using perspective drawings, including a total of 9 participants. During the second stage, spatial connections are demonstrated by plans (including 9 participant) and sections (also involving 9 participants) (Figure 4). When examining the cognitive maps, the initial stage depicts isolated spaces with no connection, while the next phase presents a comprehensive description of the entire house using specific architectural representation techniques.

SUBJECT'S INTERPRETATION IN LITERARY NARRATIVE	ds. P1-S1	ds. P1-S2	ds. P2-S1	ds. P2-S2	ds. P3-S1	ds. P3-S2	hs. P4-S1	hs. P4-S2	ds. P5-S1	ds. P5-S2	ds. P6-S1	ds. P6-S2	hs. P7-S1	hs. P7-S2	hs. P8-S1	hs. P8-S2	hs. P9-S1	hs. P9-S2	ds. P10-S1	ds. P10-S2	ds. P11-S1	ds. P11-S2	hs. P12-S1	hs. P12-S2	hs. P13-S1	hs. P13-S2	Totals
SILN/ character location						1			1				3								1		3				9
SILN / character presence		2				1			2				4		1								3				16
SILN / atmosphere																					1						1
SILN / event									1				3								1		3				8
SILN / urban context			1						1						2			1	1				1	1			7
SILN / spatial definition - spatial boundary	1	1			1	2	3	1	3	2		2	4	1			1	3		3	1	3	1	2		2	39
SILN / spatial definition - spatial movement path		1																			1	3					5
SILN / spatial definition - spatial ornament			1												4												5
SILN / spatial definition - spatial quality													1										2				3
SILN / spatial representation - diagrams		1														3											4
SILN / spatial representation - perspective drawing			1		2			1			1		2		2		5				1		4	1	2		22
SILN / spatial representation - plan drawing								2				2	1	1		1		3				3		1		2	16
SILN / spatial representation - section drawing		1		1		1		1				1	1									1		1		1	1
SILN / spatial representation - elevation drawing													4		1				1								5
SILN / spatial organization								1		1				1				3									6
SILN / spatial organization - elements							3	2					5		4		2						1				17
SILN / spatial organization - elements - car						1											1							3			5
SILN / spatial organization - elements - door			1				1	1	1	1	2		1	1	3		2	1			1	1	1		1		19
SILN / spatial organization - elements - furniture	3					1					1		1	1										1	1		9
SILN / spatial organization - elements - nature		2	1	1		1			1	2		1															1
SILN / spatial organization - elements - staircase		3		2	1	1	1	4		2		2	1	2		2	2	3		2	1	3	1	3		2	39
SILN / spatial organization - elements - water tank													1			2			1								3
SILN / spatial organization - elements - window			1										4		1				1	1			1		2		13
SILN / spatial organization - floor hierarchy		1		1		1		2	1			1		1		1			1		1			1		1	13
SILN / spatial organization - inside					1		3	3	2	1	1	1					5	2					1		1		21
SILN / spatial organization - inside - 1st living room	1					1				1		1		1								1		2		2	1
SILN / spatial organization - inside - 2nd living room										1		1		1		1						1					5
SILN / spatial organization - inside - bathroom		1					1			1						2	2			1	1	1				1	12
SILN / spatial organization - inside - bedroom		1										2		2		4	1			1	1	2		2		3	19
SILN / spatial organization - inside - breakfast room		1								1		1				2				1							6
SILN / spatial organization - inside - dining room							1			1		1		1						1		1	1				7
SILN / spatial organization - inside - hall		2								1		1		2		3				1	1						11
SILN / spatial organization - inside - kitchen		1			1				1	1		1	1	1		2	1			1		1		1		1	14
SILN / spatial organization - inside - maid bedroom										1						2				1							4
SILN / spatial organization - inside - master bedroom										1		1															2
SILN / spatial organization - inside - storage and garage										1						2						1					4
SILN / spatial organization - outside			1		1		1			2			2		3		1	2	1				1		1		16
SILN / spatial organization - outside - patio		1	1	1			1	2	1	1			1		1	2		1	1	1	1	1	2				21
SILN / spatial organization - outside - roof			1						1	1			2			1			1	1			2	1			1
SILN / spatial organization - outside - small patio																2				1							3
Totals	5	19	9	6	7	12	15	2	16	23	5	19	42	16	22	32	23	19	8	16	13	23	27	22	8	15	449

Figure 4. Subject’s illustration frequency table in cognitive maps. Source: (Author 2024)

The patio (total frequency: 22) is one of the most frequently shown spaces in cognitive maps. Bedroom (total frequency: 19), kitchen (total frequency: 14), roof (total frequency: 11), and hall (total frequency: 11) are other places that are frequently illustrated (Figure 4). The literary narrative often includes space and physical components, such as doors, patios, and staircases. These elements are also evident in the drawings made by students. While the roof does not play a significant role in the literary narrative, it is a space that students often incorporate into their sketches. This finding has the potential to shed light on the link between memory and reading experiences.

3.2. Focus group interview: subject's verbal interpretation in literary narrative

During the second phase of the study, verbal remarks regarding literary narrative were categorized based on the concepts of character, context, atmosphere / event, spatial organization, and the subject's reflection. The literary narrative context highlights the spatial arrangement with the highest intensity, which has a total frequency of 11. The verbal interpretation process lacks detailed spaces, resulting in non-varied subgroups. The comments expressly mention the terrace, with a total frequency of 4 (Figure 5). Unlike other scales, the verbal interpretation of the literary narrative specifically mentions the housing type / housing style. When analysing housing type / housing style comments presented below, one might observe variations in individuals' understanding of literary space. This implies the impact of imagination on the act of reading.

> I thought the house would be a bit modern. Participant 2
> We said to each other that it was like a regular American house, but it had become more traditional, like the open spaces. Participant 3
> At first, I thought it was an orphanage because there were just so many spaces and so many people's names. Participant 5
> It kind of gave me a countryside American vibe. It has the luxury parts of it... My main sketch was about suburban life. Participant 6
> So, whatever I drew, it was like out of nowhere; as somebody says there, they imagined a modern American house, something like that. And when I was drawing the plan, it was the first thing that actually came to mind, probably because I read it in English. Participant 9
> So, I thought it's like those very old Soviet buildings where around 1000 people live in a 5-story building. Participant 11

The students' remarks regarding the housing type / housing style also offer insights into their initial perception of the spatial narrative. The comments indicate that the imagining process of the space involves cultural definitions and associations. For instance, participants 2, 3, 6, and 11 contextualize houses within a cultural framework in their narratives. As participant 9 pointed out, the names of the characters in the screenplay, as well as the language, have an effect on the imagining process. Noticing the cultural divide (between the reader and the author) can also be seen as a constraint in imagination. The comments of participant 9 illustrate this restriction as the inability to conceive the architectural designs of a building associated with a remote culture. This elucidates the reason why participant 9 depicts a certain space from a distinct viewpoint in its initial impression sketches.

> But the problem for me was to depict what I felt after reading the script, because the distance from my culture to the culture of Mexico is far away, and I'm not experienced enough to understand what the architecture of Mexico is. So, from what I noticed, we haven't seen the building from far away; we haven't seen it from the top. So, I couldn't imagine the structure of the building plan. Participant 9

SUBJECT'S INTERPRETATION IN LITERARY NARRATIVE	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	Totals
SILN / character location						1								1
SILN / character presence					2	1				1		2	1	7
SILN / cultural context			1					1			1			3
SILN / general idea					1		1		1	2				5
SILN / social context												1		1
SILN / urban context						3			1	1				5
SILN / atmosphere						1								1
SILN / event						2								2
SILN / time						1								1
SILN / spatial organization		1		1	2		2			1	2	1	1	11
SILN / spatial organization - elements					2					2				4
SILN / spatial organization - elements - staircase					1									1
SILN / spatial organization - housing type		1	1		1	3			1		1			8
SILN / spatial organization - inside										1	2		1	4
SILN / spatial organization - outside							1							1
SILN / spatial organization - outside - patio		1			1						2			4
SILN / subject remembering					1									1
SILN / subject's feeling						1								1
SILN / subject's reflection		1	1					1	3		1			7

Figure 5. Verbal interpretation: concept frequency table in literary narrative. Source: (Author 2024)

3.3. Focus group interview: subject's verbal interpretation in cinematic narrative

The students primarily incorporated spatial organization, narrative meaning, ambiance, and cultural context in their comments following the watching experience. While the level of frequency may not be as strong as in the scales of sketching and verbal interpretation of literary narrative, viewers discuss spatial arrangement within this scale in a highly concentrated manner as quoted below (Figure 6).

> The upstairs are more different than what we thought, with a more traditional feel and open spaces. Participant 3
> But in the movie, all the rooms appear to be connected. There's no wall or door. Yeah. It's like, you know, open space. They separated them by columns and beams, not walls and doors. Participant 4
> When you watch the movie, it's very detailed and specific. Participant 5
> In the movie, there was a lot going on and the spaces were so related and like they were kind of a unit; it wasn't like the water then separated, but also it was mainly focused on the house, the interior itself. Participant 7
> The house is more separated than my imagination. Participant 8

Literary narrative contrasts the viewers' perceptions of spatial arrangement with their initial imaginings. The comments suggest that imagination has a significant role in shaping the intellectual creation of the scenario and space. The audience perceives home as a fragmented space in literary narrative, whereas they recognize that the

portrayal of space is more comprehensive in cinematic narrative. In the context of cinematic narrative, the elements of atmosphere, mood, and event are more distinctly delineated in contrast to their counterparts in literary narrative. Moreover, the data reveals the capacity of creating new immaterial /atmospheric connections through cinematic narrative.

> When I watched the movie, you can see it's like the clay, like the stone tiles, the Mexican, like a kind of Spanish, like traditional, and you can't really perceive those things when you're just like reading, but when you watch the movie, it's kind of just gives you the exact context of everything. Participant 5
>
> Industrial revolution on the London side, where it's a bit gloomy, it's rainy, it's mushy, and it's kind of a survival life. Maybe it's black and white because of that, or maybe actually the director thought of it like it has to look gloomy, sad, and kind of different from what he wrote. Participant 6

SUBJECT'S INTERPRETATION IN CINEMATIC NARRATIVE	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	Totals
SICN / character attitude						1								1
SICN / character presence	2					0								2
SICN / community						1								1
SICN / cultural context					2	1	1							4
SICN / general idea						2		1		1				4
SICN / lifestyle						1	1							2
SICN / urban context						1	1		1					3
SICN / atmosphere	1				1	2								4
SICN / event						1	1							2
SICN / narrative meaning	2					1	1							4
SICN / spatial organizaiton - inside							1							1
SICN / spatial organizaiton - outside										1				1
SICN / spatial organizaiton - outside - roof							1							1
SICN / spatial organization			1	2	1		1	1						6
SICN / spatial organization - elements				1	1					1				3
SICN / subject reflection							1		1					2

Figure 6. Verbal interpretation: concept frequency table in cinematic narrative. Source: (Author 2024)

CONCLUSION

This study scrutinizes the subject's perception of literary and cinematic narrative through the movie Roma, which focuses on the concept of space within the context of a house. The study examined how architecture students perceive and interpret literary and cinematic narratives on a spatial scale and how the alteration of narrative types affects the way we perceive and understand it.

Finding 1. In the visual representation (sketches) of space from the literary narrative, the physical elements that make up the space are more prominent than the atmosphere, mood, and event.

The cognitive mapping data visually interpreting literary narratives reveals that students receive the stimuli presented in the literary narrative and interpret them by referring to their own mental storage. In this study, it is thought that the structure of the literary narrative may be effective in the perception of the literary space. The spatial multiplicity observed in the drawings is an expression of the richness in physical materiality of the script, as revealed by this study. Formulating the research topic with regards to the space/home is also a productive approach in making this deduction.

Finding 2. The difference in interpretations of events and actions in the verbal representation of space between the literary narrative and cinematic narrative shows that reading the script might allow a literal perception of events, obscuring the nuances and metaphors.

The change in the students' perception as the reader and viewer is most evident in the quote from participant 6.

> In the text when they were defining after the school, they are on the roof and plane. When I initially read it, it felt like the story they were telling about the kid being shot. I thought these kids were being shot. Really. Yes. I thought they were actually dead. That was the case in the whole thing. I also like, you know. Because they say she's cleaning her hand, that they are shots. Yes, she's running towards the kid. It feels like, OK, something is wrong. But then you see him like, OK, there's these kids playing on them. Participant 6

This might be related to the sensuous channels each narrative is communicating through. The literary narrative is perceived by the act of seeing a symbolic set of signs, namely the language, while the cinematic narrative is perceived by the act of both seeing and hearing the atmospheric elements. So, the literary narrative is more prone to abstract and literal perceptions.

Finding 3. The spaces mentioned more in the scenario are also shown in the students' sketches with similar intensity.

Remembering may also be related to the interaction potential of spaces in the scenario. The utilization of both digital and hand-drawn tools in the study's methodology could not produce any significant outcomes in the students' literary interpretation process. Nevertheless, this preliminary analysis mostly uncovers findings relating to the substance of the data. Within this framework, the cognitive mapping data for visually interpreting literary narratives reveals that students receive the stimuli presented in the literary narrative and interpret them by referring to their own mental storage. The intense representation of the roof in the sketches suggests that the power of imaginative action and events can effectively aid in remembering the literary space, even though it is not mentioned prominently in the scenario.

Finding 4. Although the literary narrative contains various spatial components, this diversity cannot be seen when students interpret and comment on the scenario verbally.

Literary narratives provide the reader with a wider range of spatial and material components. However, the perception and verbal interpretation of these stimuli are still restricted. Furthermore, students attempted to create connections by revisiting cognitive maps at the level of verbal literary interpretation. Nevertheless, the analysis of verbal interpretations about literary narrative and cinematic narrative in the later stage of the study reveals that

verbal information encompasses broader ideas compared to visual representations. The perception of literary and cinematic narratives varies due to differences in the size of the stimulus (Figure 7).

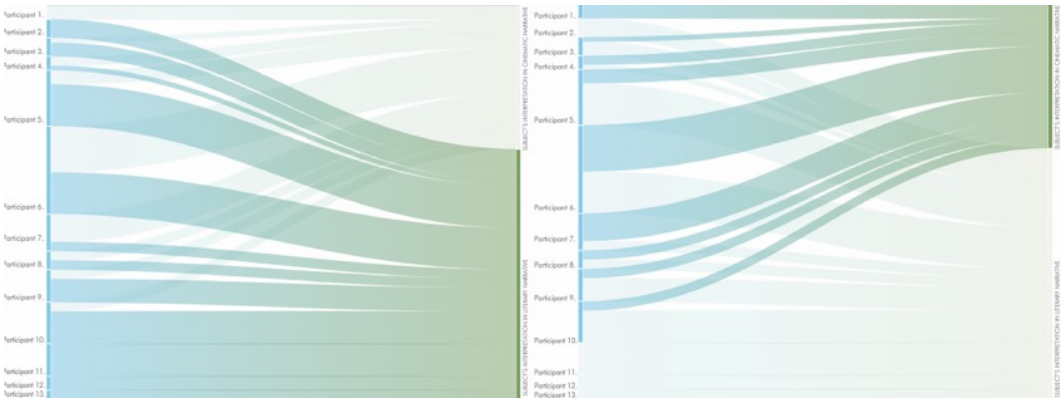


Figure 7. Subject's verbal interpretation in literary and cinematic diagrams created with atlas.ti software. Source: (Author 2024).

Finding 5. While physical elements are shown in the interpretations of the literary narrative in both verbal interpretations and sketches, immaterial and affective concepts are seen in the interpretation of the cinematic narrative.
Within the cinematic narrative, the student observes the external world rather than introspecting and analyzes both their own imaginings and the given message by engaging their personal processes of assigning meaning. As the dimensions of the stimuli in the cinematic narrative increase, the spectator starts to form new connections while interpreting the narrative. Within this framework, the cinematic narrative exposes the immaterial nature and affective impact on the viewer's understanding.

As a conclusion, this study provides a base for the upcoming research on how literary and cinematic perceptions of spatial understanding vary from each other in architectural education. Specifically, considering the significance of using narratives as appetizers in architecture education, it can be investigated how architecture students perceive space in relation to literary and cinematic narratives. In this perspective, different literary and cinematic narratives can be discussed with further studies. When constructing and assessing the narrative context in architectural education, it is possible to examine the potential of the reader's and viewer's roles and the narrative prior to the design process. This study can be carried forward with the question of how imagination and remembering are constructed in the process of spatial reading through literary and cinematic narrative. As a result, this study, which focuses on the subject's role and its perceptual-experiential layers, can contribute to future research regarding the understanding and transmission of evolving spatial contexts at the intersection of the physical and abstract realms at the human scale in the context of architectural education.

ACKNOWLEDGEMENTS

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Integrating Vector Control: A Large Language Model Chatbot for Interdisciplinary Design Processes

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ABSTRACT: Working across disciplines is essential to tackle the complex global health challenges faced today. One such challenge is the proliferation of *Aedes* mosquitoes in recent decades, which has led to a significant and growing public health burden. According to the WHO, half of the world's population is at risk of contracting *Aedes* mosquito-borne viral diseases (MBVDs) such as dengue, and this is expected to rise as climate change expands the predicted geographic reach of these mosquitoes as far north as Denmark by 2050. There is currently limited vaccines or preventative therapeutics for these MBVDs, which means mosquito control remains the most viable approach to reduce them. Modifications to the built environment present numerous opportunities to reduce this disease burden, such as designing drainage that prevents stagnant water that can become larval sites or utilising screening to prevent mosquito entry. Significant advancements in vector control strategies have been made in the fields of public health and entomology; however, these have not effectively disseminated into the building profession. This paper explores the development and application of a proof-of-concept chatbot platform that utilises Large Language Models (LLMs) to bridge architecture and public health disciplines, aiding the integration of evidence-based mosquito control strategies into the early stages of building and landscape design. This LLM chatbot draws information from peer-reviewed articles from leading global health journals, identified in a previous literature review. Users can easily access information on vector control approaches for their projects by asking simple questions such as, *'How can I improve my entrance space to prevent mosquitoes?'*. By curating the LLM's source information, we aim to reduce AI hallucinations, where fictious generated information is presented as fact. This paper reflects upon the opportunities and challenges of LLM tools for interdisciplinary projects identified during the chatbots development.

KEYWORDS: mosquito-borne diseases, vector control, large language model, global health, building design

1.0 INTRODUCTION

1.1 The increasing global health burden of *Aedes* mosquito-borne viral diseases

Many of the global health challenges faced today, such as infectious diseases and healthcare access, are impacted by factors spanning multiple disciplines, including fields such as epidemiology, public health, environmental science and the built environment. One such health challenge is the increasing risk of mosquito-borne viruses transmitted by *Aedes Aegypti* and *Aedes Albopictus*. Presently around half of the world's population are at risk of contracting one of the multitude of viruses these mosquitoes are vectors of (World Health Organisation, 2023). These diseases include dengue, chikungunya, Zika and yellow fever. Of these diseases, there is only a readily available and universally recommended vaccine for yellow fever.

The population and geographic spread of *Aedes* mosquitoes has risen dramatically in the last two decades. This is due to a variety of factors. Increased global populations, travel, trade, and urban expansion have helped these mosquito species spread across the globe (Shragai et al. 2017). *Aedes* mosquitoes demonstrate significant ecological plasticity and have adapted from laying their eggs in small water-filled tree-holes, to deposit their eggs in a wide range of artificial water bodies found in places of human habitation, such as water storage containers, discarded waste, drains and slumps. Higher temperatures, increased humidity and more erratic precipitation patterns exacerbated by climate change, has led to an increase in *Aedes* mosquito populations, their capacity as disease vectors and habitat range (Watts et al. 2021; Murray et al. 2020). This habitat expansion is expected to increase over the coming decades. A study by Oliveira, S. et al shown in Figure 1, modelling climate suitability for *Aedes albopictus* mosquitoes in 2050, predicts that 47% of Europe will be climatically suitable for this mosquito (Oliveira et al. 2021).

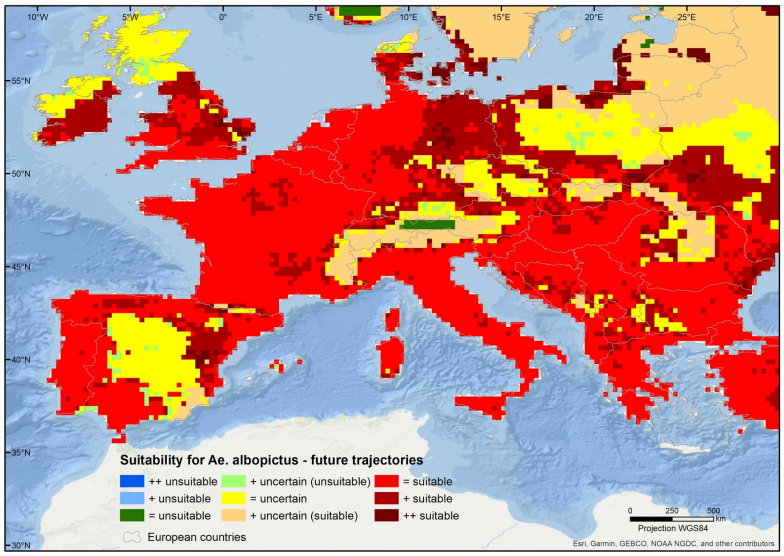


Figure 1: Projected climate suitability of *Aedes albopictus* mosquitos in 2050. Source: (Oliveira, S. et al. 2021).

1.2 Integrating *Aedes* vector control into building design

Given the growing population and habitat spread of *Aedes* mosquitoes and the limited vaccinations or treatment options for the diseases they transmit, it is crucial to implement effective vector control methods to reduce this escalating public health burden. Preventative vector control measures targeting *Aedes* mosquitoes can be a cost-effective strategy compared to therapeutic interventions or vaccinations, as they prevent the transmission of multiple diseases transmitted by a single vector. Furthermore, many of these measures are also effective against other mosquito vectors, thereby enhancing their overall public health impact. In order to develop these preventative approaches, the WHO has called for integrated and co-creational approach to vector control, bringing together specialists across different disciplines (Achee et al. 2015; WHO 2017). One such approach is the incorporation of vector control methods into the built environment. Recent studies pictured in Figure 2, have utilised building design as means to protect against mosquitoes, including novel screened facades, improved ventilation to reduce the internal concentrations of mosquito attractants such as carbon dioxide, and elevated sleeping spaces (Mshamu et al. 2022; Carrasco-Tenezaca et al. 2021; von Seidlein et al. 2017).



Figure 2: (Left) Exterior view of a Star Home in Tanzania, that utilises a variety of design strategies to reduce the risk of inhabitants contracting Malaria, including screened windows, increased ventilation and raised bedrooms. Source: (Mshamu et al. 2022). (Right) Experimental houses in the Gambia designed to test the relationship between building elevation and mosquito entry. Source: (Carrasco-Tenezaca et al. 2021)

These studies have brought together building professionals, entomologists, global health specialists and communities at risk of MBDs to develop novel approaches for vector control integrated within the built environment. Such approaches can offer other co-benefits such as improved housing conditions. Many regions affected by mosquito-borne viral diseases (MBVDs), such as Sub-Saharan Africa, are expected to experience significant population growth and increased built infrastructure demands over the coming decades. Incorporating vector control measures into future building designs could effectively mitigate the rising threat of Aedes-transmitted diseases while meeting the growing needs. Figure 3 highlights the different areas of building design that can be used to reduce the risk of MBVD transmission, identified in a previous literature review by the authors. These include landscape and water management strategies to reduce larval breeding sites, architectural and building component design to block mosquito entry and building user mobilisation to increase awareness and adoption of preventative methods.

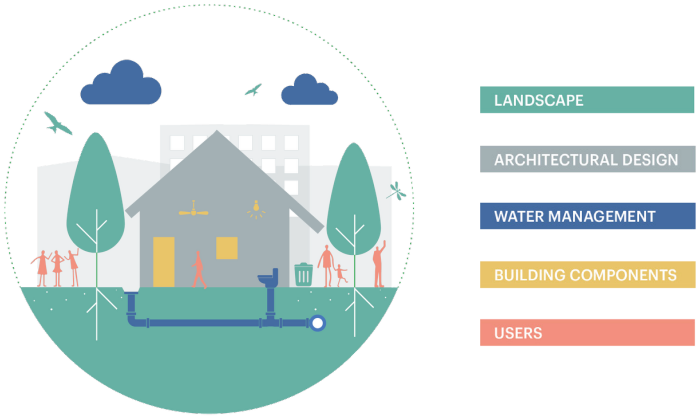


Figure 3: Diagram outlining the different areas within built environment design that can be adapted to reduce the reduce of mosquito-borne diseases. Source: (Author 2023)

1.3 Barriers to accessing vector control information for building professionals

Excluding the earlier studies mentioned, progress in built approaches to vector control has been fairly limited within the architectural discourse. Knowledge and the incorporation of vector control methods, particularly in the early stages of the design process, could dramatically reduce MBVD risk for building users and have the high cost to gain ratio when compared to retrofitting control measures (Obonyo, Pareek, and Woldu 2019). One reason for this lack of uptake may be that academic journals serve as the primary publication medium for vector control interventions, posing access barriers for building designers, contractors, and self-builders due to challenges such as academic writing style, paywalls or lack of integration into the architecture school curriculum. For built environment professionals interested to learn more, a further barrier may be the overabundance of literature available on the topic presents challenges in terms of find relevant information and staying up to date. For example, at the time of writing, a search of articles on '*Aedes aegypti*' using Google Scholar presents over 400,000 results.

1.4 Utilising large language models for information retrieval from text data sources

Large Language Models (LLMs) offer a potential tool to help improve access to relevant information for building professionals on *Aedes* vector control interventions and the latest research on other health burdens related to the built environment. LLMs are a form of artificial intelligence algorithm which use large data sets, typically consisting of text-based articles, combined with deep learning techniques to understand and summarise written information as well as creating new content. LLMs are the primary technology behind ChatGPT, (Generative Pre-trained Transformer) developed by OpenAI that was released in 2018 as well as Google's BERT (Bidirectional Encoder Representations from Transformers). LLMs can work with large text datasets which could include thousands of articles and therefore offer a powerful tool in enabling building professionals to access the wealth of information within public health and entomology literature and translate this into design approaches that could help reduce the risk of *Aedes* transmitted diseases. There are a variety of LLM projects developed by academics to utilise this technology for research purposes, such as BLOOM (BigScience Large Open-science Open-access Multilingual Language Model), an opensource model aimed to provide transparency over its 1.6TB of training data (Scao et al. 2022) or GatorTron, which is trained on over 90 billion words of text from health records, and has been tested to answer health related questions (Yang et al. 2022).

A key barrier for the use of existing AI chatbots such as ChatGPT to provide information on *Aedes* control methods and other research questions, is the likelihood of receiving fictious results known as 'AI hallucinations'. AI hallucinations are a phenomenon that occurs when an LLM misinterprets patterns within its training data, generating outputs that are not grounded in factual reality. Due to these results being based on existing factual data, these hallucinations can be highly convincing. Another challenge is a lack of control over the source and reference data from which the LLM is trained and draws the information to answer a query. It is often difficult to determine the source of an answer from a chatbot and harder to know whether this has gone through the scrutiny of the peer review process. The lack of interpretability of answers given by LLMs, like the free version of ChatGPT, raise other concerns when interpreting responses, such as the lack of clarity over why certain information was prioritised and present above other information (Kasneci et al. 2023).

This paper describes the development and application of an LLM chatbot platform, designed to help bridge the gaps between architecture and public health domains and enable better integration of evidence-based mosquito control strategies into building and landscape design. This LLM chatbot, nicknamed '*Aedes* Assistant', takes information from a database of select peer-reviewed articles from leading global health journals. Users can then easily access information on vector control strategies appropriate to their projects by asking simple questions such as, *'How can I improve entrance space to prevent mosquitoes?'*. By selecting the LLM's article-based source information, we aim to reduce fictitious AI hallucinations.

2.0 METHOD

2.1 Development of the *Aedes* chatbot

To reduce the likelihood of generated AI hallucinations and ensure responses were based on high quality sources and improve interpretability, we aimed to create a chatbot that was powered by an LLM, such as OpenAI, but used information to answer queries based on a curated knowledge database of peer reviewed journals. An electronic literature review was conducted using the PubMed database with the search term '*Aedes'* and mesh term '*vector control'* or '*insect control'*. From the body of literature available on *Aedes* vector control interventions (3,367 articles), we screened for doubles using Zotero and whether they concerned or could be applied to the built environment. For example, the large body of articles focused on the sterilisation of aedes mosquitoes or genetic modification as a means of control were not included. From this, 82 articles were identified that contained relevant control methods related to the built environment.

2.2 Building a knowledge database

At the time of creating the project, whole PDFs could not easily be uploaded or copied pasted directly into commonly available, low-cost LLMs such as the free version of ChatGPT. When uploading large documents, there is a risk of hitting the token limit due to the amount of information the LLM must decipher, therefore making it uneconomical to retrieve data. We therefore needed to create a database from selected PDFs articles that the LLM could easily draw information from. The PDFs were split into smaller 'chunks' of text, the length of which is smaller than the token size that the LLM supports. Each text chunk is then vectorised and given a series of embeddings that measure the relatedness of the text. These embeddings enable easier searching, clustering, anomaly detection and classification of the text (OpenAI Platform 2023). This allows for the smaller embeddings to be compared rather than the larger chunks of text. These embeddings are combined into a Semantic Index which forms the knowledge base. We used LangChain (Langchain 2024) to connect OpenAI's LLM to our own knowledge base.

A copy of the code for the Aedes chatbot is available here:
https://colab.research.google.com/drive/1tPYQfs9Xw5jsq0tF6hwX1zcoVFVPKWb5?usp=sharing.

2.3 Creating queries for the *Aedes* chatbot

Figure 4 describes the process of information retrieval from the article database and how this is used to generate a response to a given query. In order for the user to ask a question to the chatbot, an embedding is made based on the question's text. A semantic search is then carried out on the knowledge base from the question embedding. A series of ranked results are retrieved from the knowledge base, correlating to the relatedness to the query. These results are then interpreted by the LLM to generate a comprehensible response that is fed back to the user as an answer to their initial question.

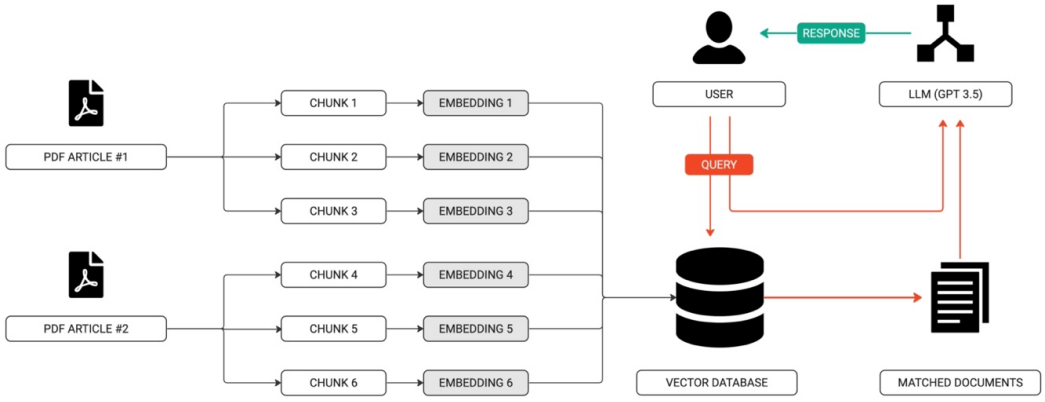


Figure 4: Process of information retrieval, showing how PDFs are separated into smaller chunks that are then embedded and stored in a vector data base. When a query is raised by the used, this vector database is searched to find which chunk is likely to contain relevant information. Those chunks are then fed to the LLM along with the query that is used as the basis of the response. Source: (Author 2023)

2.4 Testing the prototype *Aedes* chatbot

A first working prototype chatbot using python was developed in Google Colab (Google 2017), shown in Figure 5. For initial testing of the application, 11 articles were chosen at random from a previous literature review of *Aedes* vector control interventions and stored in an online Google Drive root folder which the language model can access. UnstructuredPDFloader (Langchain 2024b) was used to read the PDF files which were then divided into chunks based on length and vectorised to create a database of embeddings for the LLM to draw on using LangChain. The model was connected to the OpenAI GPT 3.5 LLM (OpenAI 2022) with a unique OpenAI key. The chatbot was designed to provide simple recommendations on how to alter or modified the built environment to reduce the risk of contracting an Aedes-borne disease, such as dengue, based on the literature contained in the knowledge database. Additional code was added to provide the reference of the source paper that the answer was taken from. The quality of the responses was assessed by asking the chatbot a series of simple questions and follow up questions, prepared and reviewed by the authors, a qualified architect and computer scientist. We identified issues with the chatbot's responses and identified strategies to improve the quality of the answers for a future version of the chatbot.

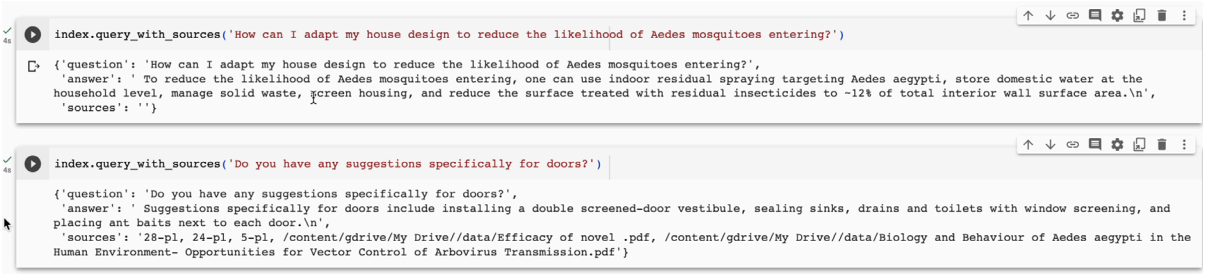


Figure 5*:* Image of chatbot interface developed in Google Colab, showing a query entry and response. Source: (Author 2023)

3.0 RESULTS

Table 1: Sample questions and responses from the Aedes LLM chatbot. Source: (Author 2023)

Query	Response
"How can I adapt my house design to reduce the likelihood of Aedes mosquitoes entering?"	"To reduce the likelihood of Aedes mosquitoes entering, one can use indoor residual spraying targeting Aedes aegypti, store domestic water at household level, manage solid waste, screen housing, and reduce the surface treated with residual insecticides to ~12% of the interior wall surface area."
"Do you have any suggestions specifically for doors?"	"Suggestions specifically for doors include installing a double screened vestibule, sealing sinks, drains and toilets with window screening, and placing anti baits (traps) next to each door."
"What plants could I use to reduce mosquitoes?"	"Plants such as O.gratissimum, moringa oleifera and fungi have been reported to be used as repellants against mosquitoes."

Example questions and responses are given in Table 1. A qualitative assessment of the responses found that for most queries given, an appropriate response was returned that was both relevant to the built environment and based on information from within the scientific literature, however there were some limitations to the answers received. We outlined the limitations and issues identified in Table 2. These included: a limited variability in the responses, with different questions receiving the same or similar answers, inclusion of irrelevant information, the cost associated with making each query, source biases and limited length of the responses. For each of these limitations we were able to identify strategies that could improve the quality of the query responses. These improvements included: increasing the number of articles in the knowledge database, optimising the LLM's response persona, improved PDF chunking and exploring the use of Opensource LLM's, such as LLaMa, Alpaca or GPT4All.

Table 2: Summary of issues identified during testing of the Aedes LLM chatbot, and potential areas of improvement. Source: (Author 2023)

Issues Identified		Strategies for Improvement	
1	Responses are relatively limited in variety, in some cases different questions received the same or very similar answers.	1, 2, 4, 5	Increase the number of articles included in the knowledge database.
2	Some responses include information that is still related to *Aedes* mosquito prevention, however, has little relevance to the query, for example describing drain modifications to a query concerning doors.	4, 5	Modify the 'persona' of how the LLM responds. For example, the model can be programmed to ask with the persona of a researcher to obtain a more academic response.
3	There is a cost associated with every query due to the OpenAI being a paid LLM. The test cost was approximately $0.1-0.3 per query with the test database.	3	Utilise an opensource language model such as LLaMa, Alpaca or GPT4All
4	Preference for certain sources over others in the test database.	1, 4, 5	Create text chunks that have overlap between the paragraphs to improve information retrieval.
5	Responses are often short in length, around one sentence, lack detail.	1, 2, 4, 5	Optimise how the PDF text is 'chunked', i.e. if it split by paragraph compared with divided based on text length then information is less likely to be split across multiple 'chunks'.

4.0 DISCUSSION

Given the rapid advancements in the field of artificial intelligence (AI) and the significant investment required to develop well-functioning large language model (LLM) applications, the Aedes Assistant chatbot was created as a proof-of-concept to investigate the challenges and potential benefits of integrating these technologies into cross-disciplinary architectural projects. The assessment of the chatbot demonstrated its potential as an advisory tool for building environment professionals during the early stages of the design process, particularly in contexts with a high prevalence of Aedes-borne diseases. The chatbot was able to identify relevant control strategies and apply them to the design of the built environment. However, there were still several areas where the quality of the responses could be improved.

The ability to create a custom knowledge database presents various opportunities for ensure oversight over the quality of the source information and carry out tasks on large datasets that would otherwise be very time-consuming. For instance, a landscape architect seeking to identify local plants that mask or absorb mosquito attractants like CO_2 could provide the chatbot with botanical studies and text on the local flora in their context. The chatbot could then quickly pinpoint the plants that are both local and meet the requirements to absorb attractants, a task that would be labor-intensive if done manually.

One limitation of the text-based chatbot format is that the responses will inherently be descriptive rather than visual. In its current capacity, the chatbot can provide text information on different design approaches, which can then be interpreted and developed further by building professionals using the interface. To address this limitation, the chatbot could be integrated with a text-to-image generator, such as DALL·E 3 or Midjourney, to create visual representations of the generated responses.

The financial cost of using OpenAI's LLM presents a barrier to the adoption of such technologies. Open source LLMs, such as LLaMa, Alpaca or GPT4All, offer a promising alternative. This is particularly relevant for Aedes-borne diseases which disproportional affect Low- and Middle-Income countries, and therefore free and open-source tools could allow great access and impact. There are also access barriers to the articles needed to build a robust database for LLMs to drawing information from, such as journal paywalls and the cost to research teams and scholars publishing open access articles. Given the pace of change within the field of AI and the continuous updating required, these open-source models are reliant on a strong community of unpaid programmers to maintain them.

The use of LLMs for interdisciplinary projects would still require extensive oversight of source information and responses to ensure that the included research meets rigorous academic standards. It would also require a thorough understanding of how these answers are generated and their interpretability, which will become increasingly difficulty as the complexity of these models increases over time. LLMs are still largely in their infancy, and there are numerous resource, socio-economic and political challenges these tools will bring, such as the environmental impact of the energy required to compute each query, ensuring job security for previously human done tasks replaced by AI, and how to navigate intellectual property laws for algorithm training when these models have access to the entire internet (Thirunavukarasu et al. 2023).

CONCLUSION

The development of the Aedes Assistant chatbot highlights the potential of customisable LLM applications to assist building professionals working on interdisciplinary projects by helping them gather relevant information, particularly in the early design stages, from fields outside their own expertise. These tools can help facilitate greater understanding and collaboration between disciplines, enabling the synthesis of knowledge and perspectives from various fields. This interdisciplinary approach is crucial for tackling complex issues, such as the increasing health burden of *Aedes*-borne diseases, which require coordinated efforts across sectors. However, there are also significant challenges with LLM tools. As these generative AI technologies rapidly advance, it will be essential for users to maintain critical oversight of the source data and responses to ensure their interpretability, validity, and applicability. This will require careful evaluation of the data quality, biases, and limitations inherent in the LLM's knowledge base and staying up to date with developments within the field of AI.

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Architecture of the Known and Unknown: Defining and Inhabiting Peripheries

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ABSTRACT: The establishment of an edge, of limits, or a periphery, is fundamental to architecture. It is the foundation of the difference between the known and unknown, inside and outside, the zone of significant energy transfers, and the making of 'place.' The term 'placemaking" may be a cliché, but there is an essential truth in the concept that makes it worth re-evaluation and definition in the context of current discourse. With that in mind, this paper will investigate how architectural peripheries are established, how they operate to mediate inside from outside, the transfer of information, and how humans then fully establish their possession of a place in the world.

This paper investigates (1) how architectural peripheries are established and their intentions; (2) the context of the familiar: how the known prepares us for the unknown; (3) how edges may not simply be a recognition of differences, but the invention of difference; (4) how difference between inside (known) and outside (unknown) is more than a conclusive barrier, but a mediation of degrees of enclosure; (5) how human activities occasion familiarity or possession of a place; (6) the notion that recently we have experienced an inversion of the inside as the place of contentment and outside as the location of unease; and (7) preliminary conclusions, mainly, the case for openness and vulnerability as modeled by a range of edges and the possibility of architecture as a model for the productive entanglement of known and unknown.

Citing specific aspects of architecture and the natural world from diverse cultures in which the values of edges, information transfer, human interaction, and designed spaces are represented, this paper examines the nature of peripheries, the inhabitation of edges, the making of degrees of enclosure, and the particularizing layers of space that intervene between inside and outside that create "difference."

KEYWORDS: known, unknown, surprising and familiar, edges, periphery

INTRODUCTION

Architecture has always insinuated itself into the unknown as it is invented and re-invented, and located, structure by structure, in unfamiliar or undeveloped terrain in order to establish someplace that is to become a "known." This "known" would be a place that is deemed safe and secure, capable of being "possessed," predictable, manageable, familiar, comfortable, and engaging. This is accomplished, initially, by the architectural act of establishing a physical periphery, an edge, a boundary, that distinguishes inside from outside. This is, of course directly related to the notion of establishing a "place," which Suzanne Langer referred to as the establishment of "ethnic domain." (Langer 1953, 100)

Architecturally and culturally, an edge signifies the making of a 'place', the domain that supports human inhabitation. (Langer 1953, 100) Inside this place is where relative certainties become available to us. But when we position ourselves at the edge and consider the outside, conceptually and psychically, we encounter the unknown: that which our designed boundaries are meant to manage for us. We generally assume, and with some justification, that these edges separate us cleanly from something. But, they do more than that. They mediate the territory between known and unknown in ways that connect us to that which is unfamiliar and enhance our understanding of both.

1.0 METHODOLOGY

As an investigation into architectural edges, the zone between inside and outside, known and unknown, this study cannot be all-inclusive. Instead, it will suffice to be selective and suggestive, focused on the examination of seven specific points worth consideration.

With that in mind, this paper investigates (1) how architectural peripheries are established and the range of their intentions; (2) the context of the familiar: how the known prepares us for the unknown; (3) how the establishment of edges may not simply be a recognition of differences, but, in fact, the deliberate invention of difference; (4) how the difference between inside (known) and outside (unknown) is often more than a conclusive barrier, but may be a mediation of degrees of enclosure across which information is exchanged, (5) how human activities occasion the familiarity or possession of a place; (6) a consideration of the notion that in recent times we have experienced something of an inversion of the inside as the place of contentment and outside as the location of unease; and (7) some preliminary conclusions, mainly, the case for openness and vulnerability as modeled by a range of edges; and the possibility of architecture as a model for the productive entanglement of known and unknown.

2.0 EDGES

2.1 The establishment and constitution of architectural edges

The establishment of an edge is intrinsic to architecture. The understanding of limits or a periphery is essential to the making of architecture. The periphery is the foundation of the distinction between inside and outside, the creation of here and there. It is the zone of significant energy transfers. It is the difference between the predictable and unpredictable, the known and unknown. And, as we will see, the constructed edge has the power to reconstrue, accommodate, and invert known and unknown.

The wall is the basic unit of security. It establishes privacy as it reinforces the integrity of the individual. It mitigates perceived threats from the outside, for example, in the form of weather, which is, additionally, a threat to the material integrity of our edges, our walls and roofs. An edge, when constituted of natural materials, weathers and develops; it often looks better over time, but requires frequent attention lest its tendency to yield to weather leads to deterioration, a capitulation to the unknown.

The construction of our walls represents, at the same time, what we think of as our mastery of a natural world, which has been tamed to serve our purposes. The edge organizes, enforces patterns, and orders us. The irony here is that we make walls and roofs and then we need to find safe ways to make holes in them again. We need light, air, views, and accessibility as much as we need deliberate peripheries. For these reasons, our edges are nearly always permeable. And this permeability requires attention. Our doors, windows, curtains, shutters need to be in the right place, they mustn't admit water, and they usually need to permit us to see out, often without others seeing in. This (apparent) one-way permeability appears to confirm our successful management of the unknown. We curate intrusions.

Edges do double duty: they are ambiguous. Robert Venturi wrote: "Architecture occurs at the meeting of interior and exterior forces of use and space," which clearly points to the fact that interior and exterior forces press on edges and shape them. (Venturi 1966, 88-89) Suzanne Langer also wrote about this meeting of forces:

> …architecture as *envisagement of an ethnic domain*, has some interesting consequences...architecture proceeds from the inside to the outside of a building, so that the façade is never a thing separately conceived, but like the skin or carapace of a living creature is the outer limit of a vital system, its protection against the world and at the same time its point of contact and interaction with the world. (Langer 1953, 100)

In their role as accommodations, edges acquire special qualities. Beyond the establishment of a boundary, they offer special kinesthetic and psychic experiences of the simultaneous known and unknown. There are special qualities of feeling associated with the experience of being at an edge. Although the banality of most construction shrinks from the potential for authentic expression of any heightened experience, there is a natural thrill, a gasp, associated with being at or near an edge, particularly when that edge is articulated by a dramatic change of level, geography, or accentuated view. Consider natural edges such as the seashore, the canyon, and the pier; and designed edges such as the wall, the tower, the cliff, the window seat or bay window, the balcony, the rooftop. Even those of us who are immune to the dizziness of acrophobia have experienced the gripping, near-fearful physical reaction to seeing the ground from a height of more than a single story, the view down into a canyon, the sight of the sea or lake from a pier or dock, as we cannot help but imagine what one false step might bring.



Figure 1: Living at the edge of the known and unknown: A window seat at the Louhisaari Manor House, Askainen, Finland. Source: (Author 1987)

The bay window, which, by definition, is located at an edge, positions us to float magically over and into a landscape, subject to an imaginable fall, but comforted, tucked into a human-scaled seat. (Figure 1) We are projected into the delectable and contradictory consciousness of mastery over a great view while confounding imminent catastrophe; situated in comfort, yet engrossed in the peril of the unknown. We seek the emotional charge of things that threaten—if we also feel safe.

2.2 The encounter between the known and the unknown

The familiar is the context for the unfamiliar. What the cited edge-challenging examples share is this exchange: the known prepares us for the unknown by making the latter bearable; and in a reciprocal way, the unfamiliar makes the familiar more profound and astonishing. The known is comprehended in a new way. The familiar plays host to the unanticipated, heightening the experience of both.

More than once, the expectation of a secure edge has evolved into more than that. The Roman emperor Hadrian (76 - 138 AD) built his eponymous wall across the north of England to defend the empire's hold on the furthest western reach of the Roman Empire from "the dreaded Caledonians—those supposedly "poison-breathing

savages," who, for the most part, casually tended their sheep. (Volner 2019, 51) Instead of strictly enforcing security, the wall attracted people to it. Romans enlisted its foreign troops exclusively to watch over its borders, which, in yet another way, brought together people from around the empire to trade and to partake of the benefits of Roman technology and civilization. Hadrian's Wall and its guardians drew small communities, whose inhabitants traded with and worked for the Romans. Intended to repel, the wall became an attractor, (Volner 2019) bringing together the known and unknown, the surprising and the familiar.

Opportunities to take advantage of the ambiguous periphery have expanded in the modern era with the reassignment of structural responsibilities from bearing wall to column grid. As evidence, Robert Venturi and Denise Scott-Brown endorsed experiences that they referred to as "both, and." (Or as we say in the axiom expressive of our time, "two things can be true at once.") The both/and condition is a version of Venturi's earlier formulation, "ordinary and extra-ordinary." Venturi said that he and Scott-Brown: "...learn from the ordinary as well as from the extraordinary." (Belogolovsky 2018) These observations call upon the observer to look closely at things that may, at first, seem familiar, but are not necessarily so.

Similarly, conditions that at first appear to preclude another condition, instead may turn out to be complementary. Lisa Heschong explored this experience in her book, *Thermal Delight in Architecture,* in which her most striking observation is how humans take so much pleasure in thermal and daylighted situations that are rich in conflicting sensations: being outside on a cold day, with snow on the ground, but in clear sky and blazing sun; or of jumping into the cold water after sitting in the marginally-tolerable inferno of a sauna. (Heschong 1979) These both/and experiences also may occur at five designed edge conditions: transparent edges, articulated edges, inhabited edges, layered edges, and embedded spaces.

In the case of *transparent edges*, where there appears to be no edge, the transparency and translucency present ambiguous peripheries where the known and unknown overlap each other. At the Glass Pavilion, in Toledo, Ohio, USA, the edge at first appears to have been eliminated. (Figure 2) The two layers of glass that define the perimeter of the building (and most interior spaces) serve primarily to regulate the thermal environment, and minimally to define inside and outside. But it becomes apparent that the many layers of glass, including those at the building perimeter, establish layers of reflections and re-reflections that preclude unencumbered visibility. The glass records the known and unknown and repeats it.



Figure 2: Transparent edges: Glass Pavilion, Toledo, Ohio; SANAA, 2006. Source: (Author 2023)

Articulated edges respond circumstantially to specific interior and exterior forces: those of the site, program, light and no light, heat and cold. (Figure 3)

Inhabited edges enable us to live within spaces carved out of a wall, establishing a zone of simultaneous habitability and security at the periphery. Thickened but still limited in depth, this massive wall condition capitalizes on the fact that people enjoy tucking themselves into spaces that are closely scaled to their bodies, enhancing the feeling of security, while stationed immediately adjacent to the unknown. (Figure 4)



Figure 3: Articulated edges: UCSB Faculty Club, Santa Barbara, California; MLTW 1968. Source: (Author 2012)

The small, carefully scaled space, especially when adjacent to a much larger, monumentally scaled space or, poised above and immediately next to that which is unknown or threatening, resolves the discomfort, and affords us a special appreciation of the overscaled volume: "...the intimate character of these interstitial spaces..." enables us to

> ...confront, at the same time, the measurable dimension of the objects around [us] and the immeasurable dimension of the surrounding world outside. (Cacciatore 2016, 107)

In the architecture of Louis Kahn and followers such as MLTW,

> the wall, as the building's boundary, ceased to be a passive consequence of the enclosing function or the main place for the mere transmission of purely constructive or representational aspects and became the most dense and meaningful instance in the spatial experience. (Cacciatore 2016, 35)

The wall became a "living place." (Cacciatore 2016)

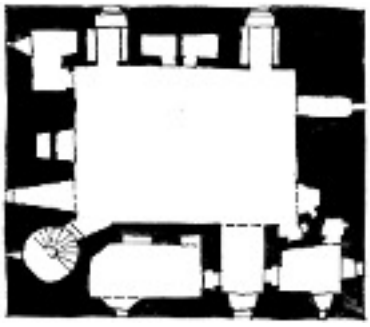


Figure 4: Inhabitable edges: Comlongan Castle, Clarencefield, Scotland, plan; late 15th or early 16th century. Source: (Author 2024)

The *layered edge* is a configuration of parallel walls and spaces that protect an inner realm in progressively interiorized zones. (Figure 5) These are solid and void compositions in which the innermost space is commonly a place of sacred or political significance, or of intense privacy, the importance of which is intensified by the evident difficulty of access through multiple edges. The repeated layers of wall and space are hierarchical, with each layer mutually supportive, aware of the other in an alternating rhythm of the known and unknown. A variant of the layered edge might be called the *embedded space,* and defined as a nestling of things inside things. (Figure 6)

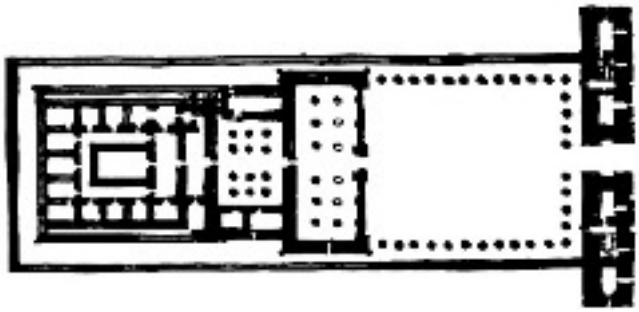


Figure 5: Layered edges: Temple of Horus, Edfu, Egypt; Imhotep, 237 – 57 BCE. Source: (Author 2024)

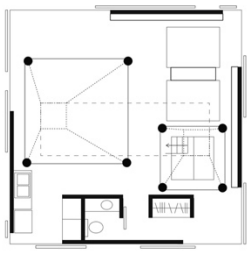


Figure 6: Embedded spaces: Moore House, Orinda, California, plan; Charles W. Moore, 1962. Source: (Author 2021)

As we go to such efforts to delineate inside and outside, it becomes increasingly evident that differentiation is vitally important to humans.

3.0 DIFFERENTIATION FOR ITS OWN SAKE

3.1 The invention of difference

What lies behind the assertion of individual space and the reinforcement of group affiliation? In architecture, we have come to call this act, "placemaking," and it may be understood as the predilection of humans to project their understanding of the world as received through individual body awareness. This may be associated with the critical individual monitoring of orientation: up, down, front, back, side-to-side, and so forth, and to project it into the

environment in order to organize and verify our safety within it. (Plowright 2020) (Moore, Bloomer 1977) Our senses of security and orientation are linked to our bodies. Our architecture makes sense if it enhances and secures these mental and physical awarenesses. The body is the center of the world and we envelop ourselves with degrees of enclosure to protect ourselves. We do this to reinforce, to gather closely what we know and can manage in the face of the unknown.

According to Ian Volner, "The [Biblical] wall of Jericho wasn't created to articulate a difference. It invented one." (Urist 2019) That is, the periphery itself transformed familiarity, creating a new distinction, inventing a known and unknown. The need to differentiate, to convey individuation, seems altogether human and as we seem to shape our architecture as embodiments of the self, it would seem entirely reasonable that we would use it to accentuate our cultural identities. (Plowright 2020)

Volner said that

> Walls inevitably engender more difference than existed prior. That begins with Jericho and extends straight through. (Urist 2019)

He writes that the wall at Biblical Jericho,

> the earliest of its kind, may not have appeared for any particular reason; instead, it created its own rationale — *the idea itself of difference* — that there could be not only an 'us,' but a 'them.' (Volner 2019, 18)

He cites archeological evidence indicating that the 10,000-year-old settlement we believe to have been "Jericho" was active during a period of peace, not war, and that the citizens' lives and activities were similar to that of groups living outside the walls. This suggests that the wall was an expression of identity, an advertisement of self, and not meant to repel anyone so much as to "invite them in." (Volner 2019, 17) Volner concludes that walls are nearly a "precondition" of culture (Volner 2019, 15). There is a term for this condition. The term, "schizmogenesis,' was invented by anthropologist Gregory Bateson to describe the tendency of individuals to define themselves in contrast to each other; he further contended that this process operates at a cultural level. David Graeber and David Wengrow, discussing pronounced agricultural and internal hierarchical distinctions between Native American cultures in the northwest of what is now the U.S., also propose that this occurs between societies, stating that "People come to define themselves against their neighbours." (Graeber and Wengrow 2021, 57)

Inherent in human nature is a need to differentiate. This is a constituent element of our need to order our worlds, to identify patterns that assist us in verifying internal security and comfort, while supporting the simultaneous need to engage with the incoming flow of the unknown. We cannot possibly relate to others and to the unknown without being able to distinguish between ourselves and others, and between inside and outside. Architecture plays an essential role in this process.

3.2 The mediation of enclosure from inside to outside: achieving degrees of enclosure

Although, we have historically constructed and described our designed edges in terms that evoke images of the impenetrable barrier, absolute opacity would make them hopelessly impractical. The history of edges provides evidence of their two-way operation, sometimes explicitly intended and at other times their complementary operation having evolved to serve multiple needs.

According to Donlyn Lyndon,

> Space, a splendid construct of the human mind, is one of several useful perceptual devices for creating the illusion of place. Sometimes it is appropriate to form it in a way that suggests indefinite extension, but seldom...The architect particularizes…Our work has for some time been concerned with establishing several degrees of 'inside'... (Lyndon 1965, 31)

This designed interchange, between inside and outside, was articulated for Lyndon and his colleagues including Charles Moore, by Louis Kahn who proposed a "servant / served" diagram. Kahn suggested, and delineated in his work, an experiential hierarchy of place, of zones for human habitation and zones that exist primarily to support habitation. As we have seen, Kahn keenly observed the differentiating and habitable functions of the thickened wall. His plan sketches of Comlongan Castle in Scotland reveal his fascination with an inhabited edge (servant space), which recognized inside and outside, defined a greater served space, and overlapped known and unknown simultaneously at the periphery.

Kahn's edges became fully-realized, inhabitable edges. (Figure 7) They were a real and effective mediation of inside to outside. Public and private, servant and served, relationships are established as defined zones, but are also interdependent as they support each other mutually in the layered, recursive, solid-void pattern of periphery and space. Important semi-public space is created and often located at the center to make a newly-fashioned, invented outside with some of the characteristics of the courtyard. The mediation of known and unknown is alternated, interdependent, and operates at a range of scales. Kahn's diagrammatic hierarchy soon becomes ambiguous. At Erdman Hall at Bryn Mawr College or at the Salk Institute in La Jolla, California, which spaces are servant and which are served?

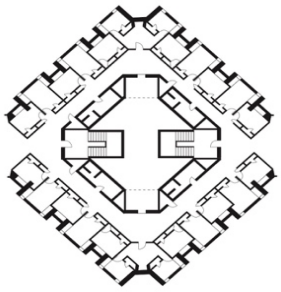


Figure 7: Inhabitable edges: Erdman Hall, Bryn Mawr College, partial plan, Pennsylvania; Louis Kahn, 1965. Source: (Author 2025)

The California architecture firm known as MLTW—Lyndon and Moore with William Turnbull, primarily—all students of Kahn, explored the possibilities and ambiguities of the servant/served, inside and outside diagram at various scales. (Figure 8) They created spaces embedded inside spaces, solids in voids and voids in solids, at large and small scales, to evoke a feeling of belonging in a particular place while having access to (knowledge of) larger, adjacent spaces. This layering of spaces, carefully scaled, arouses an even stronger sense, that which we might call, "possession" of a space. The mediation of spaces, their alternation and interdependence, placing us at the point of differentiation, lends us a sense of possession.

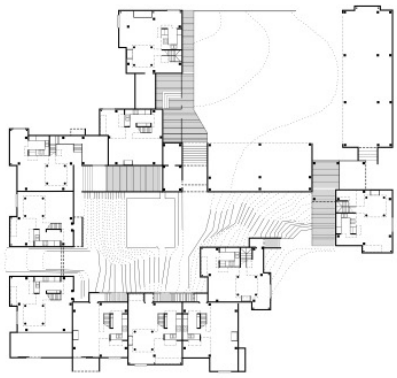


Figure 8: Embedded spaces: Condominium One, plan, Sea Ranch, California; MLTW, 1965. Source: (Author 2022)

4.0 THE POSSESSION OF PLACE

4.1 Making the known, known

How we come to possess a place**.** The exchange of ideas across peripheries, as we have seen, is not only essential; to some degree it is the objective of edges. Edges are not simple, impregnable boundaries, but lively engagements, and at their best, they are designed to be such. It is not enough to keep the bad weather or undesirable people out of our predictably safe inside places. We want to see the rain and snow, those clouds, the sleet, the hot sun, the approaching eccentrics and solicitors—from the inside. We need the view and the verification of what is going on outside. Confidence about the inside can only be verified when we can confirm outside conditions. A certain amount of disorder is acceptable—even desired—if we feel that we belong in a place. Making inside spaces whose size closely approximates the size of our bodies, and controlled views, freedom of motion, and spatial options contribute as well. Belonging in or possession of a place establishes a firm base from which to confront the unknown.

4.2 Scale

We value closely scaled spaces, the proximity to enclosure, the close tactility of bounding surfaces, to achieve the sense that we are suitably enfolded and secure. In spaces that are too large, the sense of protection dissipates and we are loose in the unknown again. (Moore, Allen, Lyndon 1974)



Figure 9: Framed views: Villa Le Lac, Corseaux, Switzerland; Le Corbusier and Pierre Jeanneret, 1924. Source: (Author 2023)

4.3 Framed views
Framed views, (Figure 9) composed perspectives of the outside world, serve to domesticate that world, miniaturizing it and making it an ordered portion of the predictable inside. The admission of daylight and its changes across the day orient us in time. The simple act of framing a view, lends a new importance to it. These transfers of knowledge across edges help us to locate ourselves with confidence.

4.4 Movement
Movement through a space, the ability to move freely, to explore, the act of measuring a space step-by-step, the tactility of walking, to participate, enable us to feel as if we possess a place. "Movement allows us to access other places, people, things." (Plowright 2020, 136) Through movement, we realize options and take possession.

4.5 Options
The simultaneity of presence implicit in these ideas, the notion that we might be free enough to manage and adjust our location in space, the "bothness" in which we experience known and unknown as we wish, engage us. This is central to a confident and measured confrontation with the unknown. In this condition we have options, the agency to act freely, the perception of control: possession.

5.0 AN INVERSION OF THE KNOWN AND UNKNOWN

5.1 Inside out
Amidst our entanglement with the unknown, we now exist in a condition in which the known and the unknown have, in a sense, been reversed. (Moore 1986) Modern architecture and cites have become deserts of placelessness. (Bloomer and Moore 1977) The security and tactility of appropriately scaled enclosure are ignored or misunderstood and have resulted in a sense of the unfamiliar and unknown. We now often find more comfort and familiarity with the outside, the natural world, than in the presumably safe interiors we have made. We have become dissatisfied with and alienated from the interior and urban spaces we have configured for ourselves. We admire and seek out nature, the complexity of its rich, overlapping orders, and its varieties of enclosure and openness. Our reversed relationship with things outside our established perimeters is an expression of our values. Our understanding of how we think about the limits of our knowledge of the world is represented and may be understood by how we manage, configure, and accommodate our physical boundaries, those that protect us from the unpredictable, while also, vitally, connecting us to it.

CONCLUSION
We are capable of configuring the surprising and familiar. We can design ambiguity and agility such that we inhabit the inside and outside at the same time, designing spaces that incorporate the outside world. For example, we welcome the development of the atrium, incorporated into contemporary architecture for daylight and thermal control, but also for views and for light from more than one side. Atriums, court, piazzas, bay windows and such devices create "degrees of enclosure," a permeable, flexible, variable periphery, open to improvisation and meaningful experiences of peripheries.

Rich edges, evident yet permeable, make us receptive to new things. Ideas are exchanged, the existing challenged by the novel, and the interchanges celebrated. This is a reckoning of known and unknown in which we can discern what we can make from what we already know—or think we know. We need these edges as they prepare us and put us in mind of ideas we have not yet confronted; they dare us to reflect and engage.

Architecture, in this way, might be a model for a rich entanglement with the unknown in that it is a physical, visible, tactile, auditory revelation of how we encounter the unfamiliar. This attitude is vulnerable yet wise, secure and receptive as it gathers the unknown and folds it into what we already know, even as those things may seem muddled. It is in the midst of this complex, messy entanglement that we comprehend the unknown.

In an allusion to what might be considered the known and unknown, Adam Gopnik recently wrote,

> There aren't any sharp margins between the irrational and the rational, between what we guess at and what we are sure of, between the wisdom we revere and the fakery we mistrust. We never know exactly who is who, or which is which, just as we will never know exactly where we are. The ambiguities…remain a lesson in whom to call wise, and why to call them so. All knowledge is labile, all identity liminal. (Gopnik 2023)

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Redefining Architectural Montage: The Synergistic Role of Artificial Intelligence in Contemporary Architectural Practice

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ABSTRACT: This study explores the application of Artificial Intelligence (AI) in contemporary architectural design, particularly in reshaping the architectural montage concept. The primary objective is to understand how AI, as a design tool, influences and transforms the methods and styles of architectural design. The research explores different applications of AI in architectural design that include assisting in conceptual design, generation and imitation of architectural styles, architectural model rendering and creation of effect images through literature review and case study analysis. The study summarises new perspectives and tools AI provides in architectural design, such as its data processing and pattern recognition capabilities, enabling designers to explore more complex and dynamic designs. The study demonstrates how AI creates and presents new architectural design concepts by analysing AI tools (such as Midjourney, Stable Diffusion, and DALL-E).Additionally, the research explores AI's ability to rapidly generate architectural content from "low information" to "high information" and to transform non-architectural information into architectural design inspiration, as well as its potential to enhance the efficiency of design communication. The findings indicate that AI impacts architectural design at a technical level and reshapes the concept of architectural montage in artistic and cultural significance. Despite specific challenges, such as ethical and aesthetic issues of AI in architectural design, the introduction of AI undoubtedly provides new possibilities for architectural practice, driving innovation and development in the design field.

KEYWORDS: montage, artificial Intelligence, architectural Design

INTRODUCTION

In contemporary architectural practice, integrating Artificial Intelligence (AI) with design redefines the concept of architectural montage. With the rapid development of technology, AI has become an essential tool for designers and plays an increasingly significant role in the architectural design process (Brennan & Lovell, 2017,490). Architectural montage, traditionally a technique of blending different elements to create new forms, has been a critical way for architects to express creativity. However, the introduction of AI is transforming this traditional concept. AI's data processing and pattern recognition capabilities provide unprecedented perspectives and tools for architectural design, enabling designers to explore more complex and dynamic design possibilities (Georgios, 2021,62).

Recent research indicates that the application of AI in architectural design is becoming increasingly widespread. For instance, AI has generated complex design concepts, optimised architectural parameters, and rendered architectural models. The work of (Krizhevsky et al. 2017:8) showcases deep learning's capability in image recognition and classification. These studies demonstrate AI's immense potential in understanding and processing complex information, bringing new perspectives and tools to architectural design. AI affects architectural design not only technically but also in terms of visual expression. Architects can experiment with new visual languages and combinatory methods using AI to create unprecedented design works. Researchers explored the potential of machine learning as a conceptual design tool in interdisciplinary collaboration and participation, highlighting the significance of AI in advancing architectural montage(Güvenç Özel 2020:385). The study by (Jonathan H et al., 2022,12) demonstrated the capability of AI diffusion models in generating high-definition videos, offering new possibilities in architectural design visualisation and animation. The research by (Yuan et al. 2020:207) discussed the relationship between AI and automation in architecture, emphasising the future interaction between humans and intelligent machines. The application of AI in architectural design transcends mere efficiency; it is deeply intertwined with expression and artistic considerations. This viewpoint reveals the potential of AI as an innovative tool in architectural montage and its impact on the development of architectural design and theory. The study by (Harapan et al., 2021,4) examined the application of AI in architectural design, particularly in forming complex conceptual designs. Their research shows that AI can assist architects in effectively analysing data and drafting in the conceptual design stage. However, it also raises concerns about the potential automation of the architect's role.

Despite the rapid development of AI applications in architectural design, research on how AI impacts and reshapes architectural montage is relatively limited. Current literature primarily focuses on the technical applications of AI, needing deep exploration into how AI integrates with architects' creative processes and affects the artistic and cultural significance of architectural design. Additionally, studies on the ethical and aesthetic aspects of AI in architectural design and its impact on the role of designers are also scarce.

Overall, this study aims to fill this research gap, exploring the collaborative role of AI in contemporary architectural practice, particularly its impact on the concept of architectural montage. By analysing existing literature and combining case studies, this research provides new insights into the role of AI in modern architectural design.

1.0 AI GENERATION TOOLS IN ARCHITECTURAL DESIGN

1.1 AI tools to aid architectural design

Some AI tools in the architectural field are utilized across various stages, including pre-construction planning, architectural conceptual design, building floor plan generation, and post-construction drawings. These applications enhance the efficiency and accuracy of the entire design and construction process. Among the various types of GAI tools, image generation tools are the most relevant to the field of architecture. As shown in Table 1, three examples of image-based GAI tools use text or images as prompts and have the capabilities of text-to-image and image-to-image generation. As research in image generation advances, 3D shape generation is emerging as a breakthrough, simplifying the design process and freeing designers from modelling tasks despite the technical challenges in collecting 3D training sets and training models.

Each tool also possesses distinct specialized functions and preferred styles. By analyzing the characteristics of the images generated by these GAI tools and comparing their applicability in architectural design, we can identify the most suitable GAI tools for architectural work. Once we understand the advantages of these tools and platforms, we can combine them into more flexible workflows.

Table 1: AI tools to aid architectural design. Source: (Author's elaboration 2024)

AI tool	Midjourney	DALL-E	Stable Diffusion	Point-E	Dreamfields-3D
Release time	*2022*	*2021*	*2022*	*2022*	*2021*
Announcer	*David Holz*	*OpenAI*	*Stability AI*	*Alex Nichol*	*Google Research*
Application stage	*Concept Design*			*Conceptual design and modeling*	
Generate categories	*image*			*3D point clouds*	*3D model*

1.2. AI in architectural design process

The architectural design process typically involves several stages, including research, proposal, modelling, and drafting, which require substantial time and effort (Figure 1). Today, the maturity of applied generative AI in image generation enables users to utilize AI for creative assistance, design proposals, rapid rendering, and batch drawing without mastering complex technologies. Thus, Designers are freed from repetitive tasks, allowing them to focus more on innovation. The architectural design workflow using image-based GAI tools resembles the conventional process but substitutes AI for humans in interpreting image information, sketching, and refining sketches.

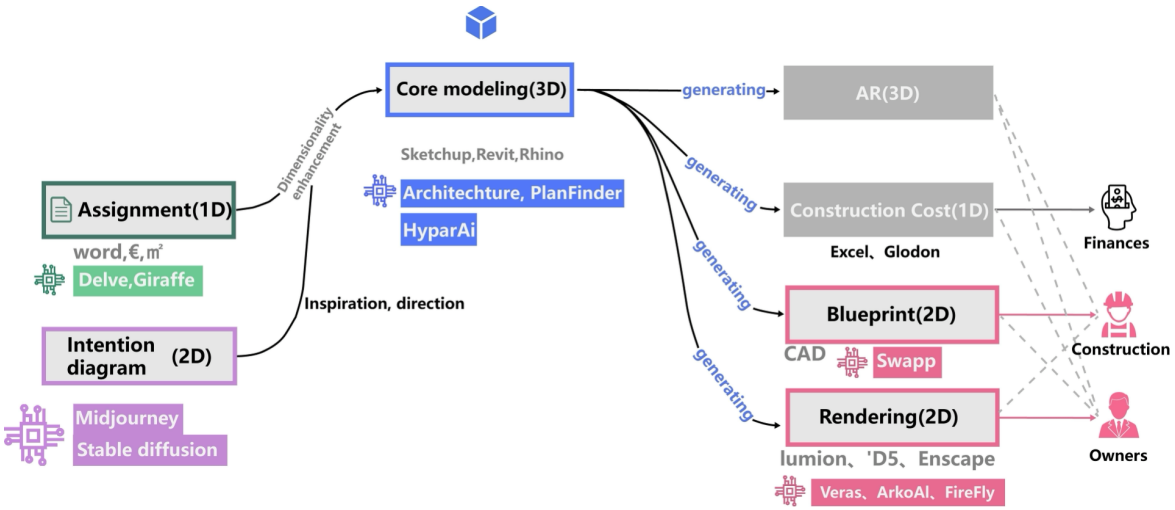


Figure 1: AI in architectural design process. Source: (Yang,2024)

2.0 GENERATION OF ARCHITECTURAL CONTENT BETWEEN LOW INFORMATION AND HIGH INFORMATION

2.1. Text to model

Figure 2 demonstrates using Hypar AI to generate building models from text prompts. Hypar AI allows architects to input specific requirements and design intents as text prompts, which the system then translates into detailed 3D building models. This capability streamlines the initial design phase, enabling rapid iteration and exploring various design options. By leveraging AI, architects can efficiently produce conceptual models that meet precise criteria, thus enhancing the overall design process and reducing the time spent on manual modelling tasks.

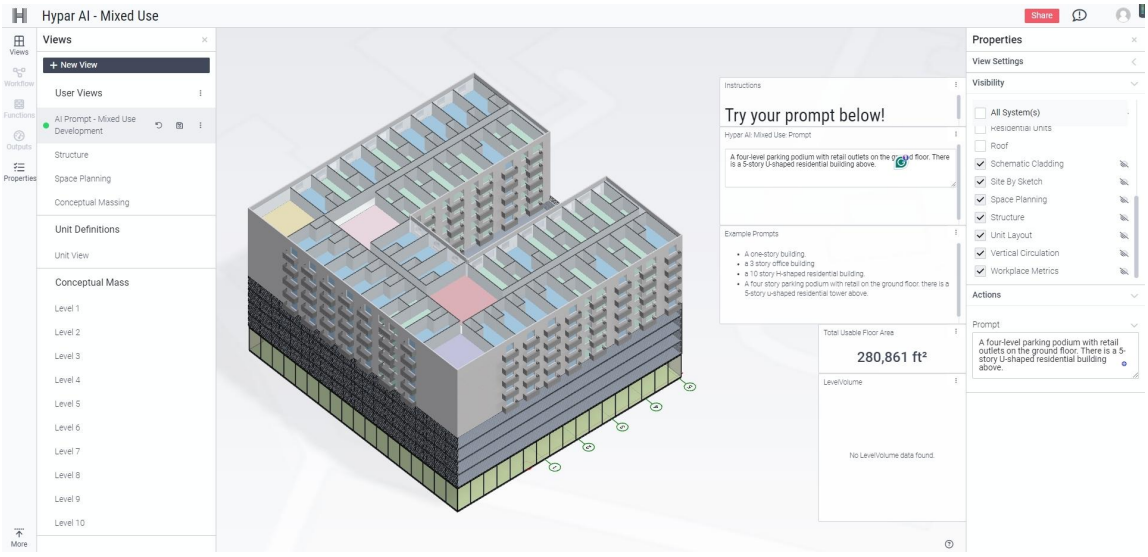


Figure 2: Use text prompts to generate building models on HyPar AI. Source: (Screenshot of HyPar AI`s website 2024)

2.2. Text to image

A brief description can instantly yield several images that highly match the description. These images can then be used to select more satisfactory results or generate similar images to compare proposals. For instance, an architect can input descriptions of a building's desired style, structural elements, or environmental context. Midjourney generates corresponding visual drafts, providing a rapid, intuitive, and creative approach to early-stage design. This AI tool excels in image style transfer, contour generation, and colour rendition, particularly useful in exploring diverse architectural aesthetics and scenarios. Its integration with platforms like Discord for command-based operations adds to its accessibility and ease of use, making it an invaluable asset for professionals seeking to push the boundaries of conventional architectural design with AI-driven creativity and efficiency (Figure 3).



Figure 3: Midjourney's operation steps of *Text to Image*. Source: (Screenshot of Midjourney,re-elaboration by the author 2024)

2.3. Image to text

Architects usually collect many design intention drawings in the early stages of architectural design. However, since the GAI tool can only accept one image as an image prompt, it must combine the CLIP algorithm with manual

conception to convert the remaining image information into text information and classify it according to the architectural professional terminology category table as text prompts (Figure 4).

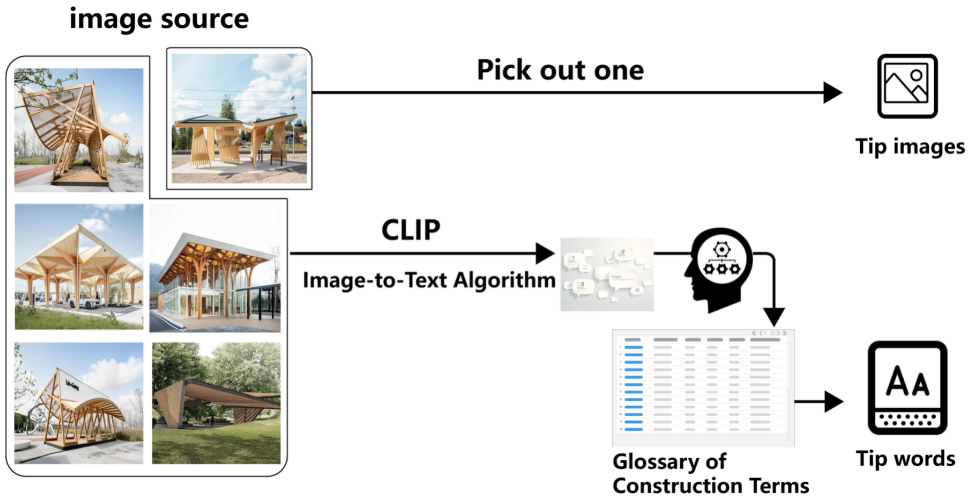


Figure 4: Use the CLIP algorithm to convert multiple images into text information and classify them according to the architectural terminology category table as text prompt words. Source: (Liu 2023)

2.4. Image to Image

AI tools can generate architectural design concept sketches based on descriptions and enrich and deepen architectural design details through their advanced image understanding and generation capabilities. For example, users can provide descriptions of architectural styles, materials, and environments, and DALL-E can generate architectural effect images that meet these requirements. Additionally, DALL-E can transform image style, converting existing architectural photos into different styles or periods, thereby inspiring architects. Unlike Midjourney, DALL-E emphasises adding creative elements while maintaining image realism and detail accuracy. Its capabilities extend beyond static image generation to include editing and transforming existing images, such as changing features of objects in an image or adding new elements (Figure 5). This makes DALL-E a powerful tool for architects exploring innovative design concepts. The functionalities of DALL-E, especially its ability to understand complex and abstract ideas, make it a valuable asset in architectural design. It gives architects a powerful tool to explore and present new design concepts creatively and efficiently.

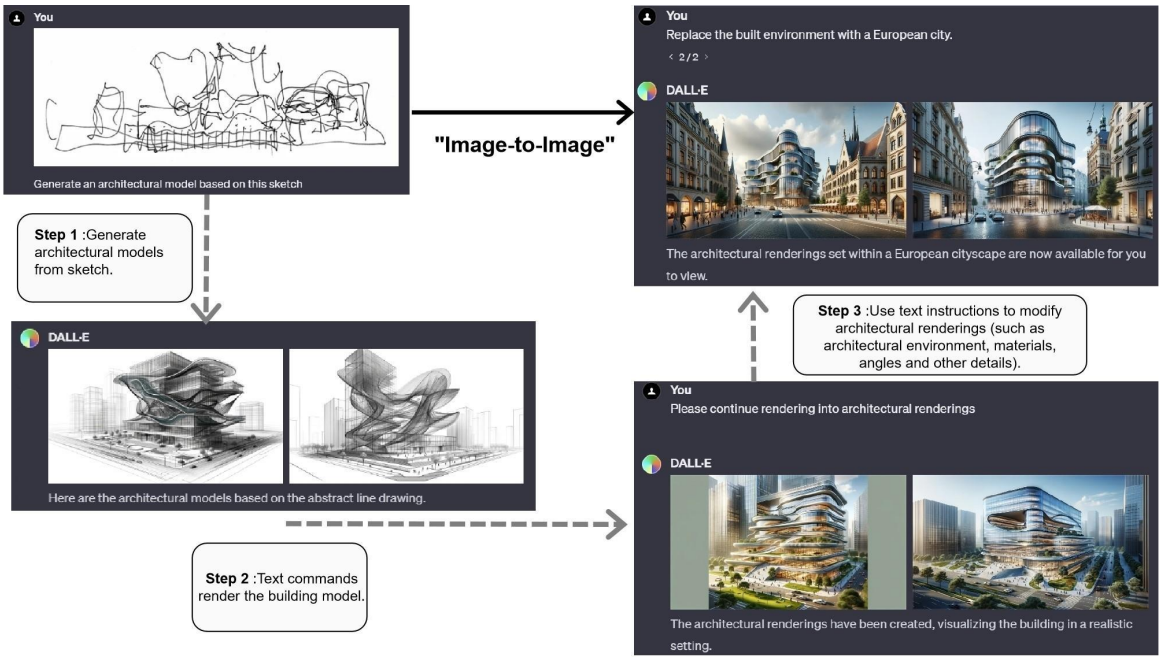


Figure 5: DALL-E's operation steps of *Image to Image*. Source: (Screenshot of DALL-E re-elaboration by the author 2024)

In 2019, Yang Liu from the South China University of Technology combined previous research and split the process from building-defined design boundaries to floor plan generation into two steps: generating floor plan annotations based on the design boundaries and then generating floor plans based on floor plan annotations. In the same year, Stanislas Chaillou from Harvard University split the experiment into multiple steps, including base, red line, doors and windows, furniture, and floor plans, and gradually added annotations of detailed information during the experiment to guide the generation of results (Figure 6). This study completed the entire generative design process

in a relatively detailed manner. Furthermore, in subsequent experiments, the room shape was more flexibly expanded into atypical flexible shapes, and based on this, the possibility of its application in outdoor spaces was explored.

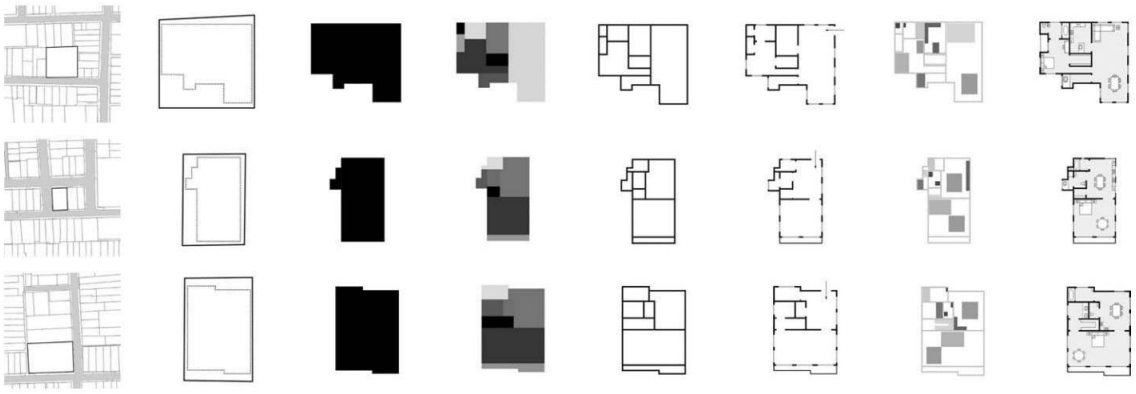


Figure 6: Multi-step indoor space design plan generation. Source: (Chaillou 2021)

2.5. Image to video

Through generative AI techniques, videos can be generated using a single architectural rendering image and an associated text description. As shown in the Figure 7, the first and second rows describe the rendering demonstration videos generated from the input image, in which the building is slightly moved and scaled while maintaining consistency with the surrounding environment. As shown in the third row, the model predicts the architectural style from different angles and ensures consistent generation. In the outlook for future technologies, the application of generative AI in partial style transfer in architectural video content paves the way for a new frontier in architectural visual presentation. This technology enables designers to replicate an overall style and, more importantly, precisely select which parts of the video should be style-transferred. Designers and researchers can explore and present architecture and urban spaces unprecedentedly.

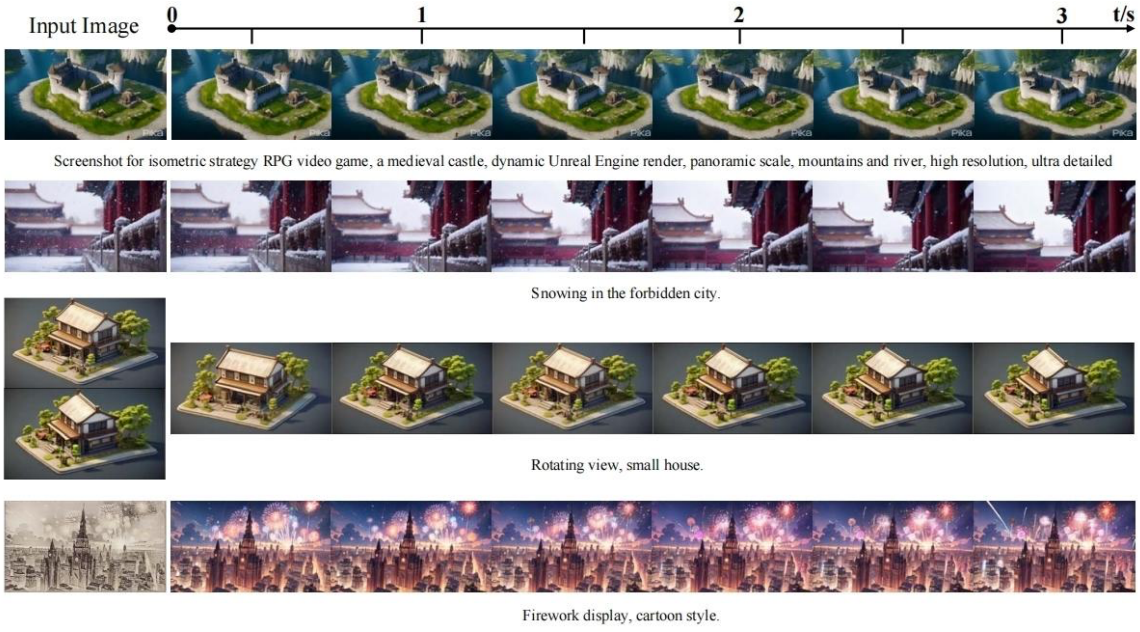


Figure 7: Generative models, such as PiKA and DynamiCrater, are capable of generating high-quality videos from images, supporting multi-angle rotation, and style transfer. Source: (Chaillou2021)

3.0 TRANSITION BETWEEN NON-ARCHITECTURAL AND ARCHITECTURAL INFORMATION

3.1. Animal to architecture

In architectural design, inspiration often comes from the most unusual elements in the human and natural world. This transition from non-architectural to architectural information can now be achieved through generative architectural design AI tools, which can transform atypical design inspirations into actual architectural plans. Generative AI models, especially those capable of style transfer, are vital in this process. These models perform exceptionally well in AI drawing, transforming objects or phenomena unrelated to architecture into inspiration for architectural design. The research attempted an architectural design related to cats. First, a basic model was designed, and then images of the model were fitted with the intended image of a cat, ultimately forming an architectural shape (Figure 8).

3.2. Items to architecture

The Architectural Intelligence Group's AI experiments, depicted here, show how randomly placed items can generate architectural designs, potentially revolutionizing design methodology by allowing an app to create architectural designs from photos, enhancing the massing study phase and making architectural creativity more accessible and controlled. Style transfer enables the generation of stylized images by blending one image's style with another's content. This technique, where initial architectural models provide content guidance and the styles of renowned architects like Corbusier, and Zaha Hadid serve as style guides, deepens the detail of manual models, allowing for innovative architectural designs that harmoniously integrate distinct styles (Figure 9).

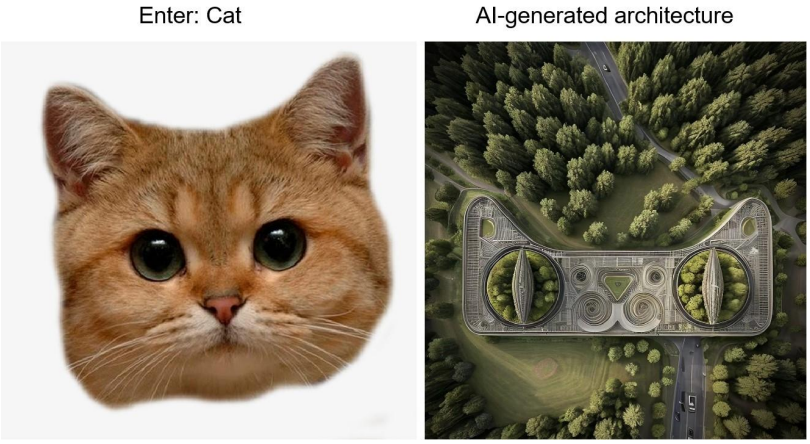


Figure 8: An architecture generated by a cat based on AI. Source: (Stable Diffusion re-elaboration by the author 2024)

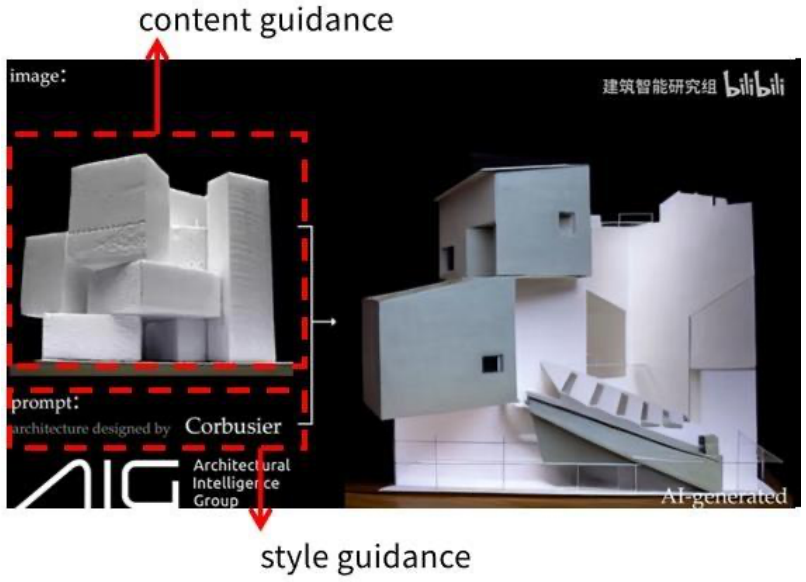


Figure 9: AI deepens the details of manual models. Source: (Architectural Intelligence Group2023)

3.3. The mycelium to urban planning

Another notable example is the research of Dr. Hao Zheng, an Assistant Professor at the City University of Hong Kong. On the left of each image is the growth process of mushroom mycelium in a petri dish, and on the right is the AI-generated urban design. Dr. Zheng used generative AI models to transform videos of the morphological changes of mycelium growth on circular agar plates into urban settlement planning models. This method demonstrates AI's ability to simulate natural phenomena and provides a new perspective for urban planning (Figure 10). In Dr Zheng's research, the AI model analysed the growth patterns of fungi in Petri dishes and applied this pattern to generate urban plans. Concepts like "biomimetic design" and "growing cities" are now more achievable with AI. The AI generates corresponding city plans from videos of colony growth, perfectly matching each stage—from inception to prosperity, saturation, and even decline. The uniqueness of this method lies in its analogy between the expansion patterns of fungi and human activities in limited spaces, analysed through the 'eyes' of AI. This analysis not only enhances the understanding of urban development but also provides urban planners with new tools and perspectives for more effective planning and design of urban spaces.

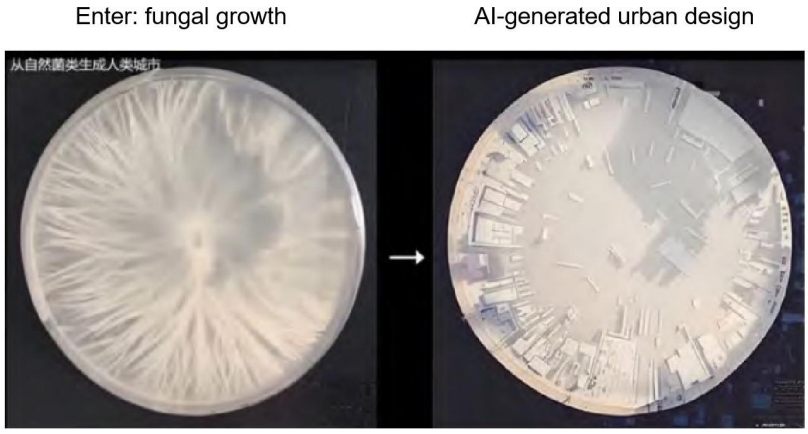


Figure 10: A city generated by natural colonies based on AI.Source: (Zheng 2023)

3.4. Building facade to music

The Project Arch to Music is innovative in blending architectural design with music composition (Figure 11). AI learns to generate musical scores based on architectural images, analyzes the pixel RGB values of the generated images, and then converts them into midi note data. The project uses datasets of architectural images and classical music and advanced machine learning models such as GANs to create a unique interdisciplinary transformation where architectural forms are interpreted and transformed into musical compositions. This method bridges the gap between visual and auditory arts and opens new avenues for creative expression and analysis.

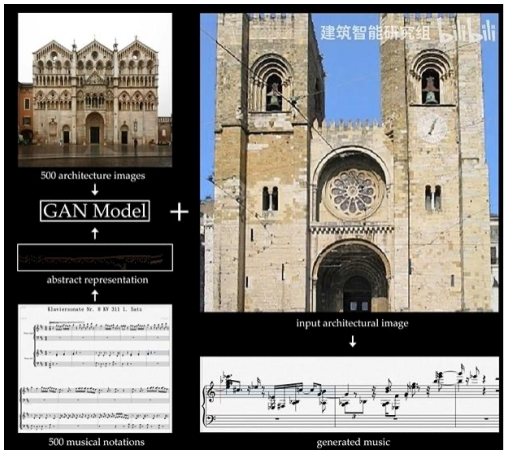


Figure 11: Training AI to turn architecture into music.Source:(Architectural Intelligence Group)

CONCLUSION

By analysing the application of various AI tools, such as Midjourney and DALL-E, in architectural design, we find that AI significantly enhances design efficiency while providing designers with a broader creative space. The application of AI in architectural montage, generating content from "low information" to "high information," showcases its ability to handle and present complex design concepts. Particularly in the transition from "non-architectural information" to "architectural information," AI's style transfer capability provides new sources of inspiration for architects. These advancements not only drive technological innovation in the field of architectural design but also open up new possibilities for architects' creative processes. However, the application of AI in architectural design also presents challenges, especially in maintaining the creative role of designers and addressing ethical issues related to AI in architectural design. While AI tools can provide rapid and diverse design solutions, architects' creativity and critical thinking remain indispensable in the design process. Overall, the application of AI in architectural practice is opening up new fields and bringing a new definition to the concept of architectural montage. This transformation is evident in technology and tools, design thinking, and creative expression. Future research should explore how AI can more deeply integrate with architects' creative processes and how to balance technological innovation with designers' roles to fully utilise AI's potential in architectural design.

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AI-informed Field Notes for a Roman Travel Experience

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ABSTRACT: This paper explores the intersection of artificial intelligence and architectural sketching in the context of international travel experiences. Traditional hand-drawn sketches, once a medium for capturing and projecting architectural visions, have waned in the face of digital photography and social media's image-centric culture. To address this challenge, a one-week workshop was designed, leveraging AI text-to-image generation technology to document Rome as the chosen experiential site. By employing AI image generation tools, participants crafted altered narratives that provided deeper insights into Rome's essence, synthesizing historical layers with innovative elements. This pedagogical approach not only exposed attendees to the cultural richness of Rome but also empowered them to envision a future that transcended conventional design boundaries. By incorporating AI into their creative process, participants bridged the gap between past and future, history and imagination, thus fostering a productive dialogue between computation, representation, and culture.

KEYWORDS: text-to-Image AI, generative AI, storytelling, travel experience, Rome

1.0 AUGMENTING THE TRADITIONAL SKETCHBOOK

The architect's sketch has a long history, serving as both a medium for capturing lived experiences and a tool for projecting visions for the future (Darley 2008). However, with the proliferation of high-resolution cameras included in every cell phone and the visually-focused nature of social media, hand-drawn sketches have been displaced by the convenience and immediacy of capturing images. Nevertheless, there is a desire to merge the ease of photography with the analytical and projective potential of sketches.

In recent times, the significance of sketches has undergone a transformation, particularly within the past year, owing to the widespread adoption of diffusion models for generating high-detail images that function as digitally native sketches (Jacobus and Kelly 2023). Since July 2022, text-to-image and image-to-image AI platforms have emerged as novel tools that have made the creation of high-quality and visually compelling images accessible to a global audience. Contemporary advancements in this technology facilitate the rapid production of images as a means to visualize ideas stemming from a natural language text prompt or photo blend. These methods provide users with multiple image iterations to choose from, all available within a matter of seconds. The rapidity with which visual ideas can now be rendered and iterated reflects a transformative shift in the creative process (Kudless 2022). Therefore, in this digital age, artificial intelligent vivid image-making has become the contemporary equivalent of the abstract napkin sketch, providing opportunities for imaginative and speculative exploration (Boden 1998).

In response to the potential of these new tools, a one-week workshop in Rome utilized AI text-to-image and image-to-image generation as a means to both document an international travel experience and design on-the-fly. Leveraging AI's immediacy in capturing and augmenting these travel experiences, participants engaged in on-the-spot imagination. This approach served to enhance the traditional practice of visiting architecture and urban sites in person, an aspect of the design discipline with roots tracing back to the Renaissance-era Grand Tour.

While the cultural influence of the Grand Tour was historically conveyed through sketchbooks and notebooks (Darley 2008), contemporary international travelers are seldom without their cameras, capturing moments on pocket-sized devices to preserve the details of their journeys. A digital camera, with its storage capacity, eclipses the limitations of traditional pencil sketches or written journal entries. On one side, photographs have the unique ability to evoke memories and emotions when revisited, providing a connection to significant times and places in one's journey. On the other, hand-drawn sketches and written narratives include inherent narrative and interpretive dimensions that may be absent from candid photos.

Text-to-image AI exhibits the potential to synthesize these elements, facilitating the creation of synthetic field notes, storyboards, and images based not only on photographs but also on descriptive textual narratives. AI emerges as a tool for constructing a digital sketchbook capable of capturing the essence, ambiance, character, texture, and colors of embodied experiences with immediacy and high-fidelity representation (Figure 1).

The authors believe that high-quality AI prompts are contingent upon the existence of an underlying cultural foundation. It necessitates a comprehensive awareness of historical antecedents and site specificity. Travel experiences play a pivotal role in cultivating this place-based cultural understanding. As Francis Bacon highlights in the essay titled "On Travel," journeys serve as a form of experiential education. While traveling enables the acquisition of knowledge within a condensed timeframe, individuals should gain information from trustworthy

sources and provide themselves with ample records of the trip so that later reflections inspire subsequent creative actions (Bacon 1888).



Figure 1: Roman atmosphere with warm light, monuments merging with environmental forces, and urban life in motion. Source: (Megan Kaminski 2023)

The Roman travel workshop allowed for the creation of an AI travel guide for a Rome that doesn't exist, through the use of AI-generated images. This process paralleled the methodology employed by architects when "mining history", finding inspiration by exploring design precedents. In this case, rather than using the static precedents found in books or online, the travel experience supplied rich experiential precedents imbued by light, sound, smell, temperature, and multiple simultaneous sensations. In fact, new outcomes were created by sampling elements in the spot from the past, projecting them into the future or a fictional, altered present (Figure 2).



Figure 2: Reinterpretation of Saint Peter's Basilica as a Scientific Institution echoing Galileo Galilei's legacy through symbolic sculptures and novel artistic icons. Source: (Ghalib Ghalib 2023)

2.0 SIMULTANEOUS SYNTHESIS

The workshop was grounded on two foundational objectives. First, transforming traditional analog sketching techniques into in-the-spot digital synthetic creations of travel speculations. Secondly, creating a narratively cohesive outcome in the format of a shareable tour book as a means of amplifying the conditions for which Rome can be imagined.

The city of Rome was chosen as an experimental and historically significant site to explore these ideas. Workshop participants engaged in a vibrant urban environment steeped in history, often called a palimpsest because of the simultaneous layers that exist and protrude through one another (Scott Brown et. al. 1984). The aim was to encourage attendees to find, contemplate, and propose AI-informed storytelling that captured known and unknown histories of Rome. This included incorporating moments, experiences, and atmospheres that both stood out to them and defined the city. The use of AI image generation provided a unique opportunity to synthesize participants'

observations and knowledge, allowing them to build a wide literacy of architectural forms, theories, and semantic elements that were simultaneously new and tied to the place.

To get the most out of this process, the workshop utilized Midjourney, a text-to-image AI tool embedded in Discord. This feature promoted real-time interaction among participants and the sharing of prompts and outputs, fostering a social learning environment that encouraged knowledge exchange. Each participant worked in a dedicated channel linked to a collective server, enabling a process of mutual inspiration and influence that pushed the overall communal creativity. The AI-informed work methodology promoted both a collaborative digital environment and a physical conversational analog where the imagination sparked during on-site visits emerged within a virtual space of dialogue rather than in isolation, amplifying the range of results and speculative exercises.

With Midjourney, the group of individuals was able to generate altered narratives that offered a deeper understanding of the city. They utilized the "imagine" and "blend" functions of the software, enabling them to create entirely new situations or blend AI-generated ideas with the photos they took during their daily visits. Many of the AI-generated images were crafted in situ. In some instances, attendees made quick text annotations of experience-specific adjectives that could be later used as part of an AI prompt. In this case, the slight delay allowed for more careful and intentional crafting between visits, upon their return to the hotel, or even at a local café.

The week-long trip to Rome was structured around thematic daily focuses, with excursions to baroque spaces, imperial monuments, and contemporary architecture. To enrich the educational experience, each participant was assigned a specific site to study beforehand, with the responsibility of delivering an on-site presentation during the trip. These presentations served as sources for supplying historical context and proposing prompts and keywords to guide the image-generation process. While conducting these on-site presentations, attendees had the opportunity to prompt on-the-fly using Midjourney. Instructors could monitor their notes and progress in Discord or provide direct over-the-shoulder insights, facilitating immediate feedback and offering supplementary guidance to ensure positive outcomes. The integration of technology and prompt-driven observations rendered the learning process dynamic and interactive, fostering a more enriched and engaging experience.

The AI-influenced travel guide presents an opportunity for collaborative and imaginative storytelling, designed for an audience of inquisitive future explorers. The tour book format acknowledges Rome's enduring status as an iconic destination, revered by intellectuals, architects, historians, artists, and tourists throughout history. The selection of this outcome type stems from Rome's historical longevity, allowing individuals to grasp its context and renowned significance over time. This pedagogical tool aims to enhance the tradition of international visitors experiencing Rome, offering insights into the fundamental principles of architectural, social, and planning dynamics that underlie the city’s profound cultural heritage.

2.1 Influence of art, sculpture, and history

The AI-generated travel guide showcased and reimagined key elements of Rome's rich cultural history spanning various epochs. One example of text-to-image generation involved overpopulating classical facades with hyper-ornamental sculptural apparatus (Figure 3). In other instances, the images juxtaposed contemporary everyday rituals, like sipping coffee or slicing a pizza, with the historical iconography of ancient tiles and mosaics. A contemporary symbol of the city, the she-wolf, was reinterpreted as a more dramatic depiction of the founding myth of Rome. In a fictional signature dynamic style by Bernini, a baroque she-wolf delivers a more consistent perspective that captures Rome's turbulent history. As the author of the AI portrayal pointed out, the AI-generated image challenged the conventional depictions of Romulus and Remus peacefully suckling from a static and placid she-wolf. Instead, in this altered reality, the Baroque sculpture depicted a multifaceted history marked by ferocity and survival, encapsulating an empire frequently embroiled in conquests and sieges (Figure 4). This alternative sculpture offers a deeper insight into the intricate and dynamic nature of ancient Roman civilization. It’s one thing for a designer to passively remark that Rome’s history is turbulent, but for a designer to roll up their sleeves and begin playing within that history represents a synthetic and educationally rich experience. The designer imagined viewing a sculpture at Villa Borghese (while in Villa Borghese) that remade the city’s mythical icon through Bernini’s mastery and arrogance.

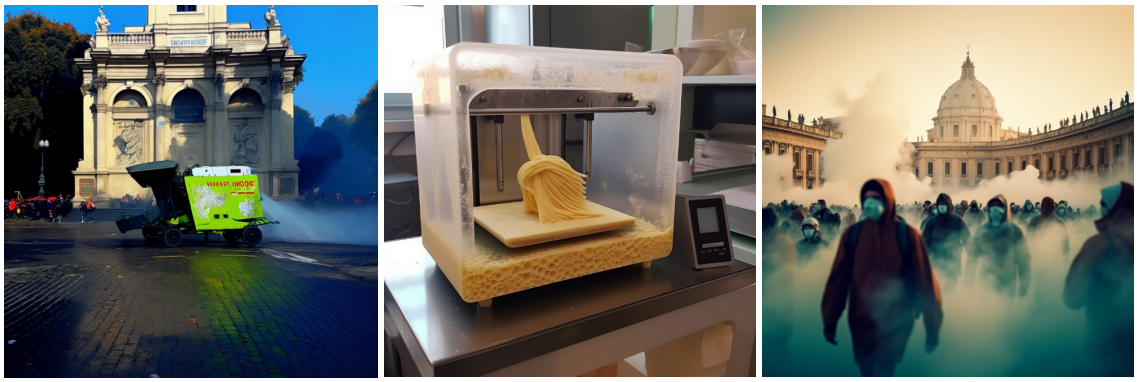
2.2 Explorations of the Roman atmosphere, food culture, and daily rituals

Immersing oneself in the intricate urban layout of Rome offers an opportunity to analyze the city's operational dynamics and the inherent challenges associated with navigating it. During our observations, the group examined the urban logistics of product distribution, from the main roads to narrow backstreets. This involved an analysis of how the city's mechanics intersect with those of vehicles, such as cars and vans that bypass monuments of immeasurable historical value to deliver pallets of goods or other commodities to the storefronts' entrances during the early hours of the morning. To enhance the city's functionality and alleviate logistical complexities, AI-generated proposals were put forth. These proposals included the conceptualization of specialized devices like street sweepers (Figure 5) and delivery bots designed to harmonize with the city's scale and contribute to its smoother operation. Another iteration of images depicted a composite urban landscape characterized by the juxtaposition of design brand showcases and artisan workshops illuminated at night. These depictions included scenes of craftsmen shaping handmade violins, illuminated with a poetic quality of light, within the corners of Piazza Farnese. When in Rome, the group was inevitably immersed in the rich and diverse food culture, a staple of Italian culture. This experience inspired them to visualize future-focused trends combining the traditional craft of food with transformative tools like digital algorithms, robotic arms, and recipe-making bots (Figure 6). On-site observations at Mount Testaccio revealed how the food culture of Rome is present throughout the layers of the city. Testaccio’s topography is composed of shards from ancient terracotta amphorae used for olive oil transportation, which have been discarded over the centuries. Participants conceived a similar stratification process occurring with modern hyper objects (Morton 2013) like discarded smartphones, reflecting how contemporary technology influences our

“anthropecienian” cultural landscape. Additionally, the symbolic grandeur of Vatican City triggered storytelling that started with a fictional Second Scientific Revolution and the restitution of Saint Peter’s as a Scientific Institution. In this vision, members of the revolution orchestrated riots in Saint Peter’s Piazza in an effort to take over the establishment (Figure 7). An army of scientists marching down piazza San Pietro contributes to appointing a new reference value and system in the hearth of the city.



Figures 3-4: Hyper-ornamental classical façade, and Baroque she-wolf. Source: (Nolan Barrios and Douglas Furia 2023)



Figures 5-6-7: Street sweeper bot. Technology-augmented Roman cuisine. Riots in Saint Peter’s Piazza after the Second Scientific Revolution. Source: (Nathan Jacquot and Ghalib Ghalib 2023)

2.3 Proposed adaptive reuse and cross-programming scenarios

Inspired by Stan Allen's method of site observation (Allen 1989), participants envisioned a "fictional present" for Rome. In this creative exercise, they contemplated a scenario where Rome's historical past seamlessly coexists with contemporary urban stratifications and programming. In this speculative cityscape, the Colosseum transcends the confines of time, continuing to serve as a venue for entertainment and public spectacles. Piazza Navona takes on a dynamic role, hosting boat contests that harken back to ancient aquatic events, while the Circus Maximus exudes a historical ambiance with its well-preserved stands. These experimental field notes drew inspiration from Piranesi's Campo Marzio, a reference project dedicated to reconstructing ancient Rome and exploring the intricate relationship between individual city fragments and the broader urban configuration. By constructing this bridge to historical continuity, new avenues of creativity and exploration were pursued. For example, the Pantheon was reimagined as a futuristic venue for e-sports, while the Baths of Caracalla found renewed purpose as a restaurant (Figure 8), a modern spa (Figure 9), or even a rock-climbing wall integrated into the ruins (Figure 10). Through these innovative concepts, which selectively embraced and redefined history, the city’s enduring presence of the past was challenged and celebrated. Participants charted cross-programmed (Tschumi 1996) alternative pathways that expanded the horizons of Rome's potential future.

2.4 Investigation into urban rituals and festivals

The Roman experience is brought to life through both tangible elements, such as historical landmarks, and intangible visual aspects, exemplified by the illumination of streets and monuments. Some AI-generated images have explored the urban impact of light reflections, examining how they interact with the city's transportation infrastructure and its layered urban landscape (Figure 11). In one example, a radical proposal envisioned a scenario of bustling car traffic in the iconic Piazza Navona (Sartogo 2014). Piazza Navona holds a special place in the thoughts of Christian Norberg-Schulz, who sees it as a vital component of the "Genius Loci of Rome", the unique spirit or essence of a place shaped by its physical, cultural, and historical context. According to Norberg-Schulz,

"Rome is a city where one feels inside while being outside," and the city's piazzas act as urban interiors (Norberg-Schulz 2014). Among them, Piazza Navona stands out as a prime example, creating a sensation of truly being "indoors" despite its open-air setting. This distinctive atmosphere has served as the inspiration behind the annual Soggiorno Film Festival held at Piazza Navona (Figure 12). The festival transforms the square into an outdoor living room, where people bring their own couches and comfortable seating to enjoy film screenings on large outdoor projections. It's a cinematic celebration that truly makes the city its living room. Adding to the magic, colorful artwork is projected onto the three fountains, enhancing the immersive ambiance of this urban space.



Figures 8-9-10: Baths of Caracalla reimagined as a restaurant (left). Baths of Caracalla reimagined as a spa (center). Baths of Caracalla reimagined as a climbing rock (right). Source: (Jakeb Jackson, Kathryn Winterscheidt, and Nolan Barrios 2023)



Figures 11-12: Parametrically-designed Baroque tempietto. Vending machine of marble putti. Source: (Megan Crumrine and Matthew Ruiter 2023)

The proposals reimagined the contemporary city by drawing upon the historical context of Rome not as plans or blueprints but rather as a casting of memory out of the past and into the future (Figure 13). The proposals were hypotheses on Rome, which would have resulted had it continued to be imagined not as a whole but proposing a palimpsest of imagery in the same way that Rome emerged organically (Argan 2014).

Workshop attendees were encouraged to engage in locally speculative thinking and employ "ifs" at will, to weave compelling and evocative proposals into the complex historical fabric of the city. By digitally synthesizing existing historical layers with their proposed or reimagined elements, AI was critically examined as a tool for disciplinary investigation. The group delved into the cultural significance of the city and developed a specific understanding of the visited sites by creating something new that is informed by that experience (Figure 14). By incorporating AI into their creative process, a bridge was established between past and future, history and imagination.

3.0 AI FOR RAPID IDEATION

Designers operate in the realm of the future, where they have the power to shape and create projects in places that do not yet exist (Allen 2000). New designs are profoundly influenced by cultural factors. Past and present are repositories of information, shaped by localized cultural perspectives and embodied experiences. The examination of precedents constitutes a fundamental aspect of a designer’s work, enabling the contextualization of ideas within their socio-political and environmental frameworks. Therefore, every creative project is inherently shaped by a combination of personal and collective knowledge, whether that of an individual or a cultural group. The human element plays a role in delineating agency within this process.

This significance is pertinent in light of ongoing discussions concerning AI-generated imagery, which center on questions of authorship. AI images are fundamentally derivative, drawing from the inputs supplied to the underlying database. The algorithms governing these AI systems function by denoising images in response to written prompts. The generation of these prompts goes beyond the simple selection of input words; it involves a comprehensive process that contextualizes the resulting output in relation to contingent factors.



Figures 13-14: Car traffic adjacent to historic monuments. Rome's piazzas as urban interiors. Source: (Ellyse Town and Douglas Furia 2023)

Creating a prompt necessitates the extraction of information from personal knowledge and existing references. An observation that emerged from the fieldwork conducted in Rome pertains to a distinct entry barrier to the workflow, not stemming from challenges related to software proficiency but rather from what can be termed as "promptus vacuous", a state of uncertainty in generating ideas when confronted with endless possibilities. To address this issue, readings and archival materials were allocated to facilitate the imaginative process, with a specific focus on designated subjects, such as anthropogenic habits in the city, prospects for human-machine coexistence within spaces of labor, or the integration of strange design elements into familiar architectural languages.

Rome's reputation as a destination became an alibi for the deliberate creation of a narratively cohesive tour book, aimed at enhancing the ways in which Rome can be conceptualized. This tour book is not intended in a spectacular way, but rather sharing a daily life, as a tourist might find it. The method is relatable to projective design work in the field, as a plausible fiction produced through design.

The adoption of a design fiction approach was instrumental in generating visual materials intended to support a charette-style fusion of design and speculative elements. Borrowing Julian Bleecker's definition, Design Fiction can be construed as the practice of crafting tangible and evocative artifacts derived from conceivable near-future scenarios, aimed at facilitating the exploration and representation of the repercussions of decision-making processes (Bleecker 2022). With the mindset of designers, the workshop attendees freely exaggerated on-site observations and analyses to see how imaginative entities might exist in the world in an altered past, present, and future.

A week of explorations yielded an extensive collection of images. The project embraced a quick and iterative method, exploring the creation of rich, high-resolution, expressive images through text prompts. Over five hundred images per person were created and curated to compile a sequence of chapters narrating an imagined Rome. All proposals were also sited within the plan of Rome. Such iterations would have been nearly impossible to achieve within the constraints of traditional week-long sketched observations on paper. These images served as the foundation for a curatorial project with the objective of discerning quality as a result of the iterative quantity. This approach viewed the technology employed as a catalyst or accelerant of human capabilities, facilitating a process wherein the intrinsic quality of the images was considered a given, and what gets value is the intellectual substance behind them.

In prior iterations of this workshop, the use of a traditional sketchbook was required and viewed as a learning device. However, the democratization of text-to-image AI image generation this past year has encouraged a shift from analog sketching, which was focused on rudimentary geometry instead, to on-the-fly digital creations for advanced diagrams of ideas situated within the richness of the city. This process produced disciplinary insights into the educational possibilities that extend beyond the limitations of physical sketchbooks, a recurring prop within design disciplines. One of the advantages of this shift is the capacity to embrace chance through the introduction of seed values, a computational entity that injects a degree of unpredictability into the process. When incorporated into the equation alongside field observations, accompanying notes, AI stylization, and parametric variability, the creative potential is expanded at will.

Unlike hand-drawn sketches, AI-generated outcomes exhibit an inherent specificity from the outset, where the first iteration, qualitatively speaking, looks like the last iteration of an exhaustive design process. This characteristic expedites the creative process by offering practical suggestions rooted in realism. This transition also negates the need for prolonged skill development; it is no longer necessary to invest years honing a particular skill, the travel participants learned the AI tools during the trip. Instead, the focus shifts towards leveraging familiarity with the cultural tools inherent to the field of design, thereby opening up an array of limitless possibilities. In fact, AI-generated images are not limited by the artist's technical skill or personal style but result from algorithms trained on a massive dataset of images. As an example, beginning design students need not put off the production of experiential depictions until they achieve the skills that come after many years of drawing.

4.0 EXPERIENCING URBANISM

The Rome travel experience employed Midjourney to produce modified narratives with the objective of fostering a more profound comprehension of the city. These narratives interlinked common or critical themes as an individual diary of the travel and leveraging subjects that emerged collaboratively among the group as a whole. Participants synthesized their observations into vivid images in real time. As an initial guideline, participants were tasked to imagine new episodes of the city in the present and projected into the future. However, occasionally, they reinterpreted iconic monuments extrapolating their nature of “objects in field” as emerged in Piranesi's depiction of Campo Marzio, which was dedicated to reconstructing ancient Rome and exploring the interplay between individual city fragments and the overall urban configuration (Tafuri 1979). In this way, attendees tweaked buildings and cultural artifacts’ histories to imagine their existence in a different present or suggest an alternative path that brought them into the modern days. These divergences created tension between architecture and the city, as well as a contrast between the desire for episodical formal explorations and greater urban order.

For many of the participants, this workshop marked their first time visiting a city, traveling abroad, and using AI technology. The excitement they felt for the vibrant culture, colors, moods, and overall experience of Rome was palpable in the AI-generated images they produced. The immediacy and photo-quality representation offered by AI technology further fueled their enthusiasm. In addition to face-to-face interactions, the participants embraced Discord as a space for sharing, commenting on, and collaboratively developing their AI-augmented experiences. This digital platform provided a forum for ongoing dialogue and facilitated the growth of ideas and concepts beyond the confines of the site visits. This type of digital meetup is an opportunity to translate the concept of “the derive”, a term associated with the Situationist movement, referring to aimless and spontaneous urban exploration, into a new potential model for engaging with a specific place or location. This model or approach may provide insights or strategies for how people can interact with and experience a particular environment in a more meaningful or unique way, possibly emphasizing the idea of exploring and documenting a place from different perspectives or through social interactions.

Attendees immersed themselves in the city, their experiences led to the development of AI proposals centered around various urban rituals, festivals, and activities that transform urban spaces. These experiences expanded the horizons of suburban participants, exposing them to the richness of urban life and sparking their imagination about the potential uses of the city. In previous workshops, participants with limited drawing abilities had hindered their capacity for imagination. However, with the aid of AI technology, their proposals embraced a fantastical vision of the future, where the convergence of people, urbanism, and technology created unprecedented and cross-programmed opportunities (Tschumi 1996).

The exploration undertaken in this study represents a novel approach to the creation of architectural notations. The field of architecture has a historical legacy of detachment from tangible forms, as it relies on the production of notations, which can be understood as sequences of instructions employing drawing conventions to articulate and convey design intentions (Evans 1997). In a parallel manner, artificial intelligence operates in a disembodied fashion, lacking inherent cultural affiliations and immersion within specific cultural reference systems.

The collaborative endeavor sought to imbue meaning into these AI-generated creations, bridging the gap between the outcomes of AI processes and the intellectual discourse that binds them together. This form of literacy is poised to assume fundamental importance in the foreseeable future, as AI increasingly integrates itself into various facets of creative processes at large. This significance also arises from AI's inherent inability to validate its sources, rendering source tracking challenging within these digital workspaces. Consequently, embracing and comprehending AI's role in this context will facilitate the establishment of a novel cultural mandate.

In alignment with Mark Weiser's proposition from 1991, which posits that "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it," (Weiser 1991) the observations made in the evolution of the discipline suggest that AI, in this sense, is destined to dissolve into our accepted practices.

Overall, this one-week experiment provided a transformative experience for the group. Individuals were able to explore the city of Rome, utilizing AI technology as a powerful tool for storytelling and documentation making a unique Grand Tour. By engaging in speculative thinking, blending history with imagination, and harnessing the capabilities of AI, they developed a disciplinary understanding of the cultural significance of the visited sites. Through their AI-augmented experiences, they captured the essence of Rome while also envisioning a future that pushed the boundaries of conventional design. This course served as a catalyst for creativity, innovation, and the exploration of new possibilities in architecture and design.

Quality in the work emerged from the iterative quantity of images produced quickly then through careful curation and selection of the most impactful. The travel experience explored the critical use of AI as a tool for undertaking disciplinary investigations to link histories and educate designers on the importance of experiencing particular sites first hand. Since designers and architects operate in the future through the creation of projective ideas, nothing helps to capture the essence or memory of a place as creating something new that is informed by that experience. This process liberated creativity and fostered a profound learning of the city's historical context and its potential for transformation and reinvention.

5.0 FUTURE DIRECTIONS

Within just a year, the progression of generative AI technology has been strikingly rapid. As part of their preparation and while immersed in Rome's historic ambiance, workshop attendees explored Midjourney's versions 3 and 4. Now, with version 6 available, we anticipate that future iterations of this experiential exploration will enhance the vitality and vividness of the work. As generative AI technology continues to evolve, we are excited about the prospect of integrating more motion-based and animation-based concepts into future workshops. This will allow us to further explore and interrogate the described approach by embracing new technologies.

As we gear up for our third workshop in Rome this year, we're shifting our approach to emphasize site-specific thinking and dynamic, real-time GIS collaborative mapping, moving away from the formatted tour book configuration. This method involves embedding AI-generated images within a shared GIS map of the city, allowing us to visualize not only the locations of the works but also to glean insights from the frequency and intensity of where participants are most active in their creative AI-image production. These insights will be invaluable for refining future workshops, adjusting itineraries, and modifying the cadence and other elements of the experience. This iteration also introduces a significant change in how participants deliver their work. Instead of requiring them to use laptops for documentation after returning from the field, we've established a workflow that supports in situ interactive outcomes. This enables participants to directly map their work onto a digital platform while still on site, fostering a more immersive and immediate sharing of their experiences. This approach not only enhances the workshop experience but also contributes to broader scholarly work in archival practices, digital humanities, storytelling, and mapping projects that create deep narratives of how individuals navigate and experience the city.

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Experimental Practice. Architecture as a Shared Field of an Exploratory Rethink

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ABSTRACT: Experimental practice – ExP, a new master course in architecture at NTNU, Norway, starts with the premise that architectural design knowledge is not made from static, unvarying facts. It is not a commodity one can purchase and therefore own it in its primary, unchangeable form. On the contrary, it is owned only when experienced through practices that are experimental and as such open to infinite processes of enquiry and critical thinking; through letting the *knowns* shift and adapt to everchanging circumstances. ExP tackles and frames its concerns with its course of action, shifts in protocols, experimental methods, and evolving strategies. That is, with an experimental set of actions tested out through the shared design experience and exchanges in real-time/space with student/teacher team members.

KEYWORDS: experimental pedagogies, full-scale, Archi-theatre, collective/embodied/experiential/contextual knowledge.

INTRODUCTION

> "The human might be the only species to have systematically designed its own extinction and seems to be getting close to accomplishing the goal. Yet it largely acts as if it cannot do anything about it, staring at the prospect of its own demise as if transfixed, even with a lingering sense of pride in this massive self-destructive accomplishment." from "Are we Human?" (Colomina & Wigley, 2016 p.15)

Experimental practice - ExP starts with the premise that architectural design knowledge is not made from static, unvarying facts. It is not a commodity one can purchase and therefore own it in its primary, unchangeable form. On the contrary, it is owned only when experienced through experimental practices and as such open to infinite processes of enquiry and critical thinking; through letting the knowns shift and adapt to ever-changing circumstances. In the face of human-designed environmental disasters and instability that everyone is confronted with worldwide, ExP suggests that what one does come to own in fact is the *not-knowing*.

While ExP does acknowledge that there are *architectly* ways of knowing, it contemplates whether these very ways have led us astray towards self-extinction. Instead of claiming to know how the design processes operate and should work. ExP issues a call to question everything that we thought were "the known" protocols in our field – architecture.

As far as ExP is concerned the only constant in the architectural design knowledge equation is a continuous process of enquiry. In other words: the architectural design knowledge lies in the very process of the enquiry, as much, if not more as in its outcome. Suggesting further that the process of architectural design may never come to "an end".

1.0 EXPERIMENTAL GROUNDING OF THE PRACTICE

1.1 When does it end really?

When the design is drafted, plotted signed and sealed; when it gets constructed; when it gets populated by its users; does it ever? There is "no stopping rule" (Rittel and Webber 1973) that challenges the dominant outcome-driven approach in design.

The question of the role and capacity of an architect arises, and consequently of the roles of all other stakeholders in the design process. Presuming that architects initiate the process with their design concepts and ideas, joined then by many others involved in the design cycles, municipality officers, engineers, construction workers, craftsmen, clients, and users, the design emerges and lives its life that spans and evolves through time - for how long and who gets to design along the way? Can we see architecture as a co-created reality, a shared field in the continuous state of making?

ExP tackles and frames these concerns with its course of action, shifts in protocols, experimental methods, and evolving strategies. That is, with an experimental set of actions tested out through the shared design experience and exchanges in a real-time/space with student/teacher team members.

The experience is recapped, rethought, and revisited here for further elaboration and growth, starting with the excerpts from the brief communicated to the students before the start of the course in the autumn semester 2022.



Figure 1: Activating the outdoor kitchen. Source: (Raonic 2022)

1.2. Excerpts from the experimental practice - ExP (AAR4612) brief

We will be designing and building in context, for a client. However, the ambitions of ExP are multi-layered and go beyond the building practice. The emphasis is on experimentation and risk-taking, but with strong theoretical grounding and reasoning of the processes.

We experiment with and investigate new ways of architectural thinking, of how we position ourselves in the context, in the design process, towards the technological, material and cultural heritage, and in nature.

We are free to question everything and to dive into the unknown.
We do that through referencing and connecting to other creative disciplines - philosophy, art (film, music..), crafts (textile crafts etc.).

Interdisciplinarity is a well-known route to innovation, but also a way to establish a system of values, narratives and wisdoms that will inform and make our architectural processes well-grounded.

Further, we go very basic - back to land, to Earth.
We ground ourselves to learn the basics all over again, to understand better what it means to be human, in relation to nature, to the planet, and to the cultural and technological heritage.

What it means to be sustainable?

Related to this is a question of the role of an architect in society as it is today but looking towards a sustainable future.

We ask: Are we human because we design (architecture)?
And if so, how ought we to design (toward a sustainable future)?

We wish to empower the practice of architectural thinking and acting (designing and building) as an exciting new research journey towards innovation that is informed by multilayers found in our cultural, technological, and natural landscapes.

At the core of every research is a journey into a discovery of the unknown, in an open-ended direction, and this is where we are heading too!

This entails practices, activities and rituals that are somewhat new to our discipline (architecture), and as such may contain the element of strangeness. Some of the *strange methods* to be employed:

1: *Walk the land*
collecting experiences, artefacts, material samples, plants, smells, sounds tastes, and intimate embodied experiences.

2: *Nesting in*
sleeping and living on the site, becoming a part of the site (figure 2)

3: *Archi-Theatre*
Performance as a mediator between Thinking and Making: Perform your architectural philosophy = Perform your architecture!

4: *Displacement*
learning through the change of context; study trip as a design instrument.



Figure 2: Nesting in. Source: (Raonic 2022)

2.0. FOUR FULL-SCALE PROJECTS AT THE FOREST & FARM TESTIMONIALS

In this section, we will stroll through students' design experiences as documented and reflected upon in the booklets/design journals that have been composed for each project/activity respectively. These notes and testimonials showcase how the framing of the course balances out the pre-set conditions with the parts that were intentionally left out un-prescribed; yet to be shaped, filled, discovered, and introduced by the students themselves. Students navigate the course of action within the given context and the set framework.

The outdoor kitchen - kitchen as a gathering place in the forest:

The fire and the table or the fire and the platform (figure 1).

Tools
A broom
a shovel
a land chopper
hammer & chisel
a lopper
ropes
women power

Small interventions
The tools as an extension of our hands. Simple tools. Keep a connection between hands and the site.
The platform, made entirely out of material from the site itself, follows the line of stones and becomes part of nature (figure 1).



Figure 3: A chicken house on wheels in the making. Source: (Raonic 2022)

Chicken house on wheels:

Working, eating and sleeping on site, together with the clients, i.e. a group of hens (figure 2). Reusing. Using the material found on the farm, only. (figure 3)



Figure 4: Horse shelter in the making reviewed by clients. Source: (Raonic 2022)

Shelter

How can we make a good frame design, how will it be used at the farm? How can this be made by us using relatively sparse tools in a limited time? (figure 4)

Materials
Timber from the trees that we cut in the forest.
Reused items from the farm.

Tools
3 Drills
2 Circle saws
A lot of screws
A hammer
A handsaw

Foundation
6 Big bold stones

4 Logs from nearby spruces
6 *Jordskruer*

Structural material
11/2 Spruce trees, freshly cut into planks.
8 Re-used corrugated metal sheets



Figure 5: Floor growing. Source: (Raonic 2022)

Room to rest in the woods

Materials harvested from the site. (figure 5-6).
Tree trunk for logs on the floor. Thinner trunks for the wall. Branches for weaving.

Materials
Logs
Branches
Stones
Soil
Blue wire
Hemp
Waterproof textile

Tools
axe
shovel
drill
hammer & chisel
ladder
blue rope
hemp
Pickaxe
gloves
measuring tape
a green box

Cleaning the site with our hands
Cut the branches, use an axe to cut down trees.
Building the awareness of the elements we chose to use.
The woven roof floats over the heavy floor (figure 6). An intimate space in the middle of nature.



Figure 6: Roof weaving. (Raonic 2022)

3.0. ARCHITHEATRE

The idea of this hybrid exercise that combines architecture, exhibition design and stage design with performance and conceptual art, was to re-open a question on space: What is space?

Architecture clearly does not hold a monopoly on space. The idea of space is something that permeates the discourse of many different fields beyond architecture, of dance, film, music, dance etc. Hence, this exercise that was introduced to the students as design task no.2, in the second part of the semester, asked them to: Design and build a site-specific Exhibition that translates all their *designerly* and any other collective & individual experiences and knowledge into a new kind of spatial narrative that will in addition be activated by their performance – ArchiTheater. (Raonic 2022)



Figure 7: ArchiTheater. Source: (Raonic 2022)

As for the initial design tasks, the objectives were to rethink design strategies and construct a discourse around questions of space and sustainability, to use locally available, locally sourced materials for designing and building their work. “The trees that grow in your backyard” as said in the lecture slides, meaning the four projects in the forest & farm were to use the material found there, on the location, in natural surroundings, while the exhibition project was to use the material found on/around campus, on the streets, in the urban context.

Archi-theatre shifted the roles of architects to artists and performers, enabling the architects to re-live their own work in the forest and on the farm, recontextualize it and re-evaluate from a different perspective. The Exhibition & ArchiTheatre operated as a stage to showcase and translate the plethora of experiences and encounters, individual and collective, from Norway to India, from theory to various craft experiences and perspectives, all to be woven together in a new spatial narrative. Finally, the architecture is shifted into a story-telling device, and an architect to a narrator.

ArchiTheater bridges between architecture and performance art and pinpoints their shared core concern: the interplay of bodies and space (Aubin 2019). It points to an expanded understanding of architecture highlighting that the movement of bodies in space is just as important as the space itself (Tschumi 2008).

Collective and individual design experiences are collected, recomposed, rearranged and articulated in a new system of meaning. The exhibition is as a design output, but also as a tool, for rethinking, reliving and an opportunity to address the fundamental questions about what it takes to make space (figure 7-8).

Students were invited to translate and *stage* their experiences and let them evolve in time, allowing for various interactions with the visitors who may become participants and add to the spatial narrative, or rearrange its parts, while impacting the whole. Architecture becomes a shared field of interaction, a non-verbal instrument of communication between the architects and visitors. Instruments for investigation. In the best tradition of Price and Littlewood' s Fun Palace "a university of the streets" and "laboratory of fun" (Littlewood, 1964), questioning what is architecture, who is an architect and who is an observer. Where is the line if any?

Architheater frames two general topic areas that it sees as forming a bridge between performance art and student's particular approach to architecture. The first concerns modes of transdisciplinary practice and the second addresses issues related to movement and temporality. The exhibition becomes a stage for rethinking architecture, while the architect's body is addressed as a design tool, that allows us to live through the design. Design is lived through not only analysed and conceptualised rationally.



Figure 8: ArchiTheater+exhibition. Source: (Raonic 2022)

CONCLUSION

Coming from the position of NOT-KNOWING, starting from scratch again, assuming all we know is open for continuous re-questioning. This is the precondition that Experimental Practice has set, in framing its curriculum. Navigated by material, cultural, natural context, design tasks, clients and many other parameters involved in a complex equation that architectural design processes and teaching/learning architecture always are, ExP lets them take their own course.

But why? It comes down to acknowledging that we, humanity, and our profession in particular are at the cul-de-sac of the era of Anthropocene and associated culture. We have been for too long acting non-critically, over-building, over-producing and over-loading the planet, without ever really challenging why, how, and what happens after; never really facing the consequences until it has become too late.

Hence, ExP invites students and teachers together to question everything that we thought were the laws of the profession, the know-hows, through framed pedagogic format, that offers several experimental strategies and methods presented and discussed in these pages. *Shift* as a primary, back-bone strategy that has taken many different forms.

We have been shifting the roles of architects to lumberjacks, to basket weavers, to sewers, to artists, farmers, weavers, performers. Students/teachers' roles have been shifting and swapping all along.
We introduced shifts in the organisation of the design process, in the order of the design & construction phases and in their duration. We cut and collect natural fibres, stones, branches and wood before we draw.

Instead of drawing and sketching on paper first, we draw in space directly with the material found on the site. We treat space-making as three-dimensional sketching. The architecture grows from the land with the material resourced locally, along as we grow from architects to becoming integral part of the context. We take time to observe, read, understand the sites intimately, and soak in the smells, sounds and atmosphere.

With strange methods, *Nesting in* and *Walk the Land*, the traditional "site analysis" shifts from rationalising physical features, measuring and observing as impartial external experts, to living on and becoming a part of the site. The role of an architect shifts to an off-grid forest dweller, along with all other forest animals.

Archi-theatre shifts architects to artists and performers, enabling the architects to re-live their own work in the forest and on the farm, recontextualize it and re-evaluate it in that way. Archi-theatre and exhibition operated as a stage to showcase and translate the plethora of experiences and encounters, individual and collective, from theory to various craft perspectives, all to be woven together in a new spatial narrative. Finally, the architecture is shifted into a story-telling device, and an architect to a narrator.

Interdisciplinarity is a well-known route to innovation, and here it has been instrumentalised to a greater extent for the sake of learning within the field but moreover for learning more about the field of architecture; about how it could be transformed into a more socially, politically, culturally, and ecologically sustainable legacy that humanity should leave behind.

The experiential, embodied, hands-on learning, that shifted the process and crossed the borders of academia, of cultures, of the discipline; having spent more time outside of (what conventionally is considered) the discipline, than within, led to quite a few invaluable gifts to collect.

This kind of experimental and non-reductionist approach not only helped re-affirm more sustainable connections with the immediate context in a real space/time, but also beyond the realm of the present moment and locus. The connections were made with the past and across the globe.

The craft intelligence and wisdoms that are treasured only in the experienced crafts people's hands, travelled through time, from Norway and India to be transferred into space-making techniques in an entirely different context, in order to do things in architecture in a whole different way:

> "In EXPERIMENTAL PRACTICE
> We ask the fundamental questions of architecture all over again.
> We go back to the basics to rethink the role of an architect in society as it is today towards a SUSTAINABLE future.
> We challenge the usual practices of SPACE MAKING and learn from other disciplines.
> We tailor the roof.
> We stitch the house.
> We grow the floor.
> We weave the wood.
> Forest, rain, sheep, stone, farmer, horse, weaver, child are our clients and our teachers."
>
> from forward to Rethinking Spaces exhibition (Raonic 2022)

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Vertical Gardens – Built Environment Education Tool In Schools In Serbia

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ABSTRACT: Built environment education (BEE) presents an interdisciplinary field of education intended for children and young people. Besides fields of architecture, urban design, art, landscape architecture, etc., it includes different social aspects such as community engagement, culture, and heritage, thus being important not only for future architects but for every citizen. On the other hand, in Education for Sustainable Development (ESD), the main topics of interest are key sustainability issues such as climate change, lack of biodiversity, sustainable consumption, etc. Likewise, promoting critical thinking and decision-making in a collaborative way, ESD coincides with methods in architecture such as participatory design. This research focuses on developing a BEE co-design method with integrated ESD components that can be applied as a learning tool. To answer the main research question of how we can successfully design vertical gardens (VGs) in schools that act as BEE tools for tackling sustainability issues, study first presents a set of educational gamified workshops aiming at the development of co-design method that includes topics of environmental, ecological, and social VG benefits, and second, its evaluation results. The workshops' input was specially developed for the ages of 12, 13, and 14 and later conducted through the collaboration of architects, a pedagogue, teachers, and students in one primary school in Belgrade, Serbia, in April 2023. This study is part of the author's doctoral research, whose related objective is the design of a toolkit for a gamified educational co-design method for VGs that can later be applicable to other schools. Therefore, this paper concludes the tested design process evaluation, suggesting recommendations for its improvement. Finally, this research contributes to filling the previously identified gap in the scientific literature on VGs' educational benefits and the urgent need for education on nature-based solutions in Serbia.

KEYWORDS: vertical gardens' educational benefits, BEE, ESD, co-design method, interdisciplinarity

INTRODUCTION

Our planet is currently experiencing numerous environmental challenges, evidenced by extreme weather conditions and disasters in built environments in recent years. These challenges have directly impacted the quality of life for citizens, necessitating urgent actions across various sectors. In the realms of architecture and urban design, the requirements for action are becoming "rapidly more demanding, complex, and interdisciplinary due to demographic, social, economic, environmental, and technological changes" (Hensel et al. 2020, 1). To address these challenges, several global strategies have been initiated, aiming to enhance environmental protection, social inclusion, and economic growth, thereby improving well-being in built environments. One such initiative is The Sustainable Development Agenda 2030 (Martin n.d.). When it comes to the built environments, a specific goal of Agenda, SDG11, was set to make cities and human settlements inclusive, safe, resistant, and sustainable (Martin, n.d.). However, according to the latest report, measuring progress towards SDG11 in Serbia remains challenging due to limited data, the nature of the indicators, and the absence of significant change. Only one out of ten indicators, namely 11.5.2 (Direct losses caused by disasters as a share of global gross domestic product (GDP)), shows measurable progress (Babović 2023, 8). Conversely, the report highlights setbacks in SDG4 - Quality Education, highlighting the increase in the number of

> students aged 15 who did not reach the minimum fixed level of achievement on the PISA scale for three basic school subjects (Babović 2023, 35)

such as math, reading, and science.

To enhance the achievement of the two mentioned SDGs, an application of educational actions, including BEE and ESD, may be an effective approach. Intersecting youth interdisciplinary education programs like BEE, where space presents an educational object (Brković Dodig, Klepp, and Million 2019) that includes various social dimensions such as community engagement, culture, and heritage, with ESD, which fosters collaborative critical thinking and decision-making while acting on sustainability issues ("What You Need to Know about Education for Sustainable Development | UNESCO," n.d.), could yield significant outcomes across multiple fields. Based on the mentioned facts, the premise of this research is that architectural and urban design processes can serve to teach about sustainable development through curriculum or after-school activities. Seeing architecture "in the service of the natural environment" and integrating "social, cultural, economic, and environmental sustainability criteria" (Hensel et al. 2020, 2), the application of research with an interdisciplinary approach is a promising course of immediate action. Besides, interdisciplinary pedagogies enable not only children and youth in general but also future architects, artists, landscape architects, urban planners, and designers to acknowledge, address, and foresee sustainability issues in the future (Hensel et al. 2020). Moreover, the close attachment of children to their parents leads to the unintentional transfer of knowledge to their parents and other adults (El-Aasar et al. 2018).

Relying further on the suggestion that there is a need for educational initiatives to raise awareness about the importance of Nature-based Solutions in Serbia (Radić Sibinović, Brković Dodig, and Million, 2025), the author positions VGs as an educational tool to address sustainability issues in schools within urban environments. Their positive effects can be observed at two levels: building-level benefits (e.g., improved building energy efficiency, internal air quality, air filtration and oxygenation, occupant health, better protection of the building envelope, reduced interior noise, and increased property value) and urban-level benefits (urban heat island effect reduction, air quality improvement, carbon sequestration, aesthetic appeal, psychological impact on urban residents, biodiversity enhancement, natural wildlife habitat creation, and sound attenuation (Safarik and Group 2014). VGs' benefits, such as social and educational, have been confirmed only descriptively (Radić, Brković Dodig, and Auer 2019). Contrarily, VGs have been widely built in schools (in developed countries such as Spain, the United States, Germany, United Kingdom) in recent years as a climate mitigation strategy, a measure for improving biodiversity, producing food, or as a teaching tool. Seeing education as an agent of change, for example, the Barcelona Schools Agenda 21 Program aimed to integrate the principles of sustainability in schools' educational programs, using exactly VGs as tools ("Spain - Barcelona - Educating Sustainable Development," n.d.). However, there is no VGs' design process developed intentionally as a BEE tool to address sustainability challenges, neither in Serbia nor in the developed world. Outcomes of such an interdisciplinary project include:

- educational gamified design process,
- VGs design that answers sustainability issues,
- and the implementation of inclusive activities within the school community.

Therefore, the key aims of this paper are to first introduce the novel developing VGs co-design method that acts as a BEE tool with ESD components and its evaluation step. Finally, the study concludes with recommendations for the method's improvement.

1.0 RESEARCH METHODOLOGY

To answer the research question of how we can successfully design VGs in schools that act as a BEE tool for tackling sustainability issues, this study adopts action research with a participatory approach, emphasizing collaboration, inclusivity, and co-creation of knowledge in one primary school in Belgrade, Serbia, in April 2023. A novel VGs' co-design method was further developed through testing and evaluation steps conducted together with school community members. Data collection was internal to the game (Gundry and Deterding 2019), which in this specific case means done by participants during five gamified process steps. The complete method was tested and evaluated in 3 days, including 12 school classes through the curriculum, one of which lasted 45 minutes according to the educational system in the Republic of Serbia. Additionally, an online qualitative survey was conducted with teachers after the workshops, as well as a semi-structured interview with the pedagogue, aiming at the evaluation. Participants' total number per role in the process is presented in Table 1, as well as the evaluation methods each of them applied.

Table 1: Workshops' participants and applied evaluation methods. Source: (Author 2024)

Participant	*Age*	*Number*	*School community member*	*Process phase*	***Applied evaluation methods***
Student	12	10	✓	Testing **Evaluation**	**Semi-structured group discussion after each step and mapping in Eisenhower Matrix**
Student	13	6	✓	Testing **Evaluation**	**Semi-structured group discussion after each step and mapping in Eisenhower Matrix**
Student	14	1	✓	Testing **Evaluation**	**Semi-structured group discussion after each step and mapping in Eisenhower Matrix**
Teacher	/	3	✓	Development (1 teacher) Testing **Evaluation**	**Semi-structured group discussion after each step and online qualitative survey**
Architect	/	3		Development Testing (2 architects) **Evaluation** (2 architects)	**Semi-structured group discussion after each step**
Pedagogue	/	1		Development **Evaluation**	**Semi-structured interview**
Researcher	/	2		Development Testing (1 researcher) **Evaluation**	**Semi-structured group discussion after each step**
Interviewed	12 - 60	32	✓	Testing	**No evaluation**

/: Not available data; ✓: confirmation sign.

According to one of the latest studies,

> … the discourse around child-framed methodologies needs to extend beyond simply listening to what children have to say, and actually begin to position children as researchers who directly influence the methodology, analysis and outcomes of a given study (Cutter-Mackenzie and Rousell 2019, 5).

A group of up to 25 children, "... which can be explained by logistical, methodological, and ethical reasons" (Shamrova and Cummings 2017, 27) was involved beyond just being a source of data, corresponding to Level 5 ("consulted and informed") of Hart's ladder (Hart 1992). Namely, children were supposed to

> work as consultants for adults in a manner which has great integrity. The project is designed and run by adults, but children understand the process and their opinions are treated seriously (Hart 1992, 12).

Accordingly, 17 students divided into 4 groups, had an important role in both phases of the VGS design process - testing and evaluation. Except for completing tasks, they were supposed to highlight all positive and negative aspects they experienced during the process after each step and to suggest ideas for improvement, thus influencing process development. When it comes to the teachers' participation, "Educating educators for sustainable development may be the starting point for further steps in Serbia" (Milutinović and Nikolić 2014, 107). Together with students, one biology and two technical education teachers were involved in the testing and evaluation of the VGS co-design process, which was especially important in analyzing the educational benefits of the complete process. Two architects and technical education teachers were in charge of providing participants with spatial, constructional, and design explanations when needed. The author of this paper, as a main project researcher, had the role of moderator and participant who collaborates with children and teachers in the co-creation of VGS design by encouraging constructive discussion with open-ended questions in decision-making moments. The process was additionally evaluated by the pedagogue, identifying challenges and recommending improvements. The final step of the testing phase included 32 interviewed school community members of different ages and roles, which was of great importance for developing future scenarios, so that the operation of VGS can be optimized, maintenance costs reduced, and its existence in the school sustainable.

According to Chukwudozie et al. (2015), one of the main challenges of the participatory approach is to record, store, and analyze qualitative data. For this reason, a research diary with short notes was kept as a way of storing data and recording key analysis. Children explained to a researcher their answers, digital photos, and sound recordings of children's key messages were taken, and each workshop ended by reflecting on research findings. Process evaluation was done by all participants using different methods presented in Table 1. Finally, to develop recommendations for the design process improvement, all data were coded thematically, which reflects the typical qualitative data analysis method (Stapleton 2021).

2.0 RESULTS

2.1 Introduction to the VGs' co-design method

To initiate the project, one primary school in Belgrade, Serbia, was selected based on the following set of criteria developed from two perspectives, spatial and educational:

- location in a central urban area
- high building density around the school
- proximity to existing VGs in open public spaces
- lack of vegetation within the schoolyard
- the school's recognition of the need to address sustainability issues and its ongoing work toward sustainable development
- the school's interest in research activities participation, as well as potential future collaboration (e.g., VGs installation process, development of guidelines for VGS maintenance, and post-project evaluation)
- the school's ability to allocate time for students and teachers to participate and engage in this research through the classes of technical education, biology, and/or ecological section activities.

After the school selection, teachers of biology and technical education were contacted and informed about the project idea and goals. Upon their acceptance to participate, consent forms were delivered to them. Thereafter, teachers enclosed project information letters and consent forms to selected students and their parents, inviting them to participate in the protocol.

Upon determining the participants, students, teachers, and other interested school community members joined forces with a researcher and architects to identify local sustainability challenges, then explore VGs' design possibilities, and finally plan its future use to act as a formal, non-formal, and informal learning tool (Million et al. 2019) in their school spaces. This co-design method was conducted through 3 days of workshops within a technical education classroom. Developed to lead participants through five different design steps (Figure 1), workshops cover topics of environmental, ecological, and social benefits of VGs, thus including components of ESD. The novelty lies in the context of Serbia with the action-oriented approach to ESD, thus including the practical application of knowledge and skills in real-life contexts, aimed at addressing and preventing sustainability challenges and promoting sustainable lifestyles (Veinović 2017).

A complete process was developed specifically to be primary school age-appropriate, aiming for children to co-design VGs. Young participants were supported in extending their inquiries through a creative set of gamified tasks as a particularly valuable data collection tool that enhances problem-solving abilities, communications, cooperation, responsibility, and imagination, and supports creativity (Brković 2013). For instance, a shuffle cards game was developed to assist children in learning about the various VGS construction types and the degree to which they impact sustainability issues. Additionally, participants employed additional decks of cards as an interactive means of learning about the different advantages of vegetation and sustainability challenges through the workshop activities. Extensions of the methodology through the children's use of their school maps also stimulate their BEE by enhancing spatial awareness and environmental perception.

> Such a participatory approach to architectural design rests on a democratic premise that everyone concerned by a design should be involved in its creation and the evaluation of its quality ("Convention on the Rights of the Child | UNICEF," n.d.).

Therefore, Table 2 presents the co-design method's components, such as gamified analysis and decision-making tools. It also lists educational components through the method's five steps in chronological order, as well as each step's output in the context of the specific primary school where the method was tested.

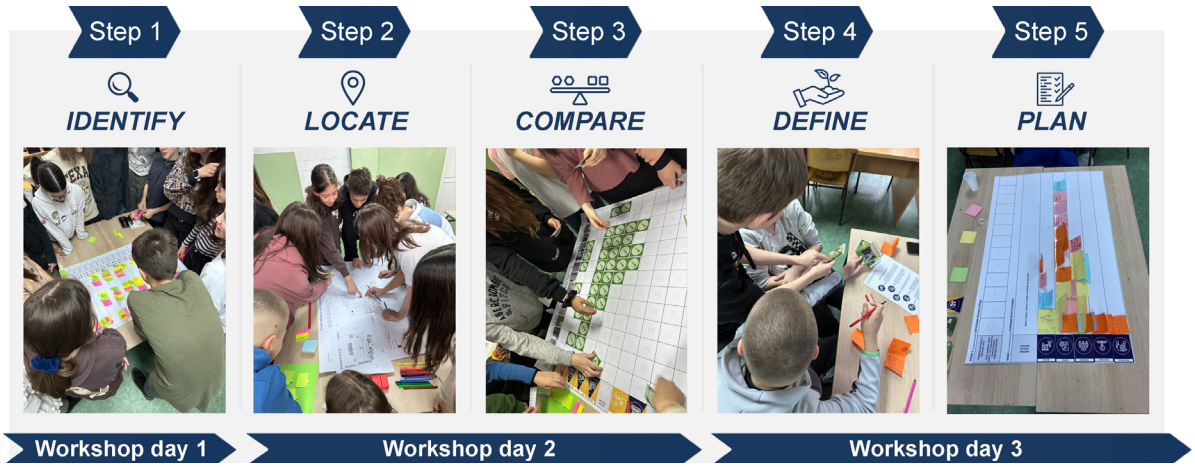


Figure 1: Schematic representation of the co-design steps. Source: (Author 2024)

Table 2: VGs' co-design and education components. Source: (Author 2024)

Step	*(BEE) Analysis tool*	*Decision-making tool*	*Step outputs*	*BEE and ESD topics*
1 Identify	*16 cards* each card presents sustainability issue that VGs can address	*1 table, red and green stickers* to evaluate and identify priority sustainability issues	Identified 6 "urgent" and 3 "less urgent" sustainability issues that VGs design must answer	*ESD:* sustainability issues that VGs can address - thermal comfort, energy saving, air quality, noise, water saving, water retention, health, safety, aesthetics of space, education, biodiversity preservation, responsible use of materials, façade existence, healthy diet, participation, inclusion
2 Locate	*1 school map and red stickers* to locate issues and identify priority zones according to the number of issues		Suggested zone 2 for possible VGs locations	*BEE:* good spatial orientation and use of 2D school building and yards plan for identifying specific school places with sustainability issues and defining spatial zones
3 Compare	*13 cards* each card presents different VGs construction type and their benefits	*1 table and checkmark symbol cards* to compare and evaluate VGs constructions	Suggested VGs construction types to answer identified sustainability issues in zone 2	*BEE:* technical aspects of VGs construction type variations: materials, size, weight, maintenance, etc. influencing VGs sustainability benefits *ESD:* nature contribution to the sustainable development at the local level
4 Define	*16 cards* each presents different outdoor plant appropriate for VGs	*1 table* for the selected plants discussion and presentation	Suggested plants that answer VGs construction type, orientation, and local sustainability issues	*BEE:* link between the built environments, nature, and art *ESD:* importance of specific plants in relation to sustainability issues
5 Plan	*Interviews and future scenarios questions* for social issues group discussions	*1 table* for the suggestions summarization	Suggested future use of VG based on social aspects: education, inclusion, participation, health, and safety	*BEE:* architecture as a creative intellectual task consisted of research and design, draws on humanity, culture, heritage, nature, and society *ESD:* basis on participatory teaching and learning methods that motivate and empower learners to change their habits and act for sustainable development

BEE: Built Environment Education; ESD: Education for Sustainable Development.

Each of the five educational VGs' co-design process steps uses a specially developed gamified analysis tool and a complementary decision-making tool. In steps 1, 3, and 4, gamified analysis tools are illustrative cards with specific questions that initiate and further support understanding of unfamiliar terms and relate them through divergent thinking to the specific spatial context of their school spaces. Questions for *Step 1 Identify* have been developed through the collaboration between the architect/researcher together with the pedagogue, to be specific age appropriate. This step was developed relying primarily on VGs' benefits mapped by the literature review by Radić, Brković Dodig, and Auer (2019). For the *Step 3 Compare*, 13 different cards have been designed to present different VGs construction types and how well each of them answers sustainability issues, based on the most comprehensive VGs construction typology developed by Radić, Brković Dodig, and Auer (2019) and empirically confirmed data. For *Step 4 Define*, 16 cards with different plants have been designed through collaboration between the architect/researcher and the biology teacher. The goal was to offer participants a variety of plant species appropriate

for VGs according to their characteristics such as orientation, maintenance, and watering demands, flowering period, and interesting facts about each plant. In *Step 2 Locate,* participants use a school map and red stickers as both together, analysis and decision-making tools, aiming to discover different vulnerable spaces in the school areas, thus defining potential locations for VGs. The only step that applies two design tools is the *Step 5 Plan*. As the aim is to imagine and plan future scenarios related to VGs' sustainable use, participants had to express their wishes on the topics of VGs' inclusion, participation, health, and safety, and present and discuss them together. Moreover, students conducted short semi-structured interviews with other school community members, such as teachers, students, janitors, cooks, cleaners, librarians, members of the choir, and parliament. They used three sets of pre-prepared questions to interview and later share and discuss results, thus defining VGs' educational and maintenance possibilities.

As students' active participation in decision-making is crucial for ensuring they have a voice in design processes and for adults to consider their contributions (El-Aasar et al. 2018), specially developed participatory decision-making tools were incorporated into each step to aid specific outputs, as well as to provide inputs for the following steps. Such tools were used after small group discussions to further evaluate results together with teachers, architects, and a researcher. Except for Step 2 Locate, each step includes the use of unique tables that enable results summarization, emphasizing what is crucial and what needs more investigation.
So far, VGs have been globally recognized as a school teaching tool for biology or art classes (Hop and Hiemstra 2013), able to inspire real-world thinking related to science, technology, engineering, and mathematics fields (McCullough, Martin, and Sajady 2018). Considering the suggestion that

> the next generation needs to learn about the environmental concerns of today and how we are addressing them (Sheweka and Magdy 2011, 599),

the newly developing VGs' co-design method could be the appropriate tool. It covers BEE and ESD subjects in two steps, while one education field is handled in three steps. Overall, they are both equally involved in the design process of VGs. When it comes to BEE, good spatial orientation and understanding and reading school building and yards maps are mandatory for the successful zoning of sustainability issues. By introducing various VG construction types and their technical, technological, and vegetation requirements—all of which have variable degrees of impact on reducing sustainability issues—students can learn about architecture, engineering, technology, art, and landscape architecture. When it comes to ESD, participants can primarily learn what are current sustainability issues and how they can recognize them in their environment. Also, they can learn about the importance of nature-based solutions in urban areas, and how nature contributes to their life quality, so as to sustainable development. Furthermore, they develop participatory skills and learn to address issues through interdisciplinary collaborative work. Finally, some of them develop a sense of belonging to the community and are motivated and empowered to further educate and act for sustainable development.

2.2 Evaluation of the VGs' co-design method - educational topics novelty

An important initial evaluation was conducted by students who were instructed to use Post-it notes with their school class and place them in their respective positions on the axis. The educational value and interest level in co-design were assessed using the Eisenhower Matrix. The results, depicted in Figure 2, revealed that students aged 12 demonstrated a higher level of knowledge on BEE and ESD topics compared to students aged 13. Participating teachers clarified that educational topics included in the VGs co-design process are not covered in the school curriculum. Therefore, it depends on the willingness of various teachers teaching the same subjects to educate children outside of the curriculum.

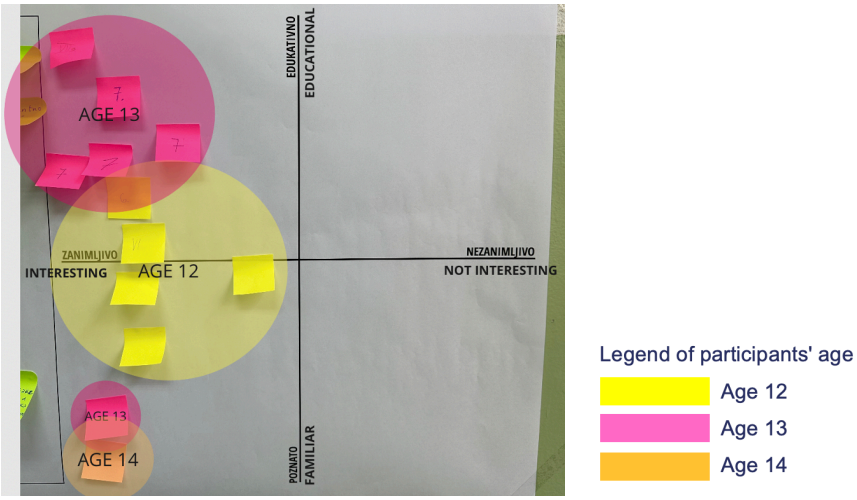


Figure 2: Students' evaluation results. Source: (Author 2024)

When children and teachers were asked to comment on the VGs' co-design process using one word, most of them described the process as interdisciplinary, interactive, innovative, interesting, and educative. Additionally, some noted that it was an excellent opportunity to form new friendships. One participant remarked,

> I like a lot all the workshops, and I would like to do them again. It was very interesting. We learned a lot of new things (Student Participant 2023).

Besides the ESD topics, the biggest novelty in the learning process for the students was the use of different BEE tools, such school map, the selection of VGs construction type based on the local sustainability issues and school needs, as well as interviewing other school community members.

According to the post-evaluation survey completed by participating teachers, VGs' co-design method could be implemented through specific after-school activities. In their opinion, those could be organized by thematic sections for students interested in caring for common school spaces and elements. Furthermore, teachers observed that students gained substantial knowledge about VGs, their significance, and the different types of VG construction throughout the design process. Notably, only those students recognized as the most active participants by teachers received the highest grades in biology and technical education.

2.3 Evaluation of the VGs' co-design method - technical difficulties

Issues with the tools' design were identified in two steps. In *Step 1 Identify*, participants used Post-it notes of different colors more times, which made the evaluation process difficult. The same colors visually indicated a connection between incompatible comments, thus hindering data analysis. Further challenges existed with the cards' design in *Step 4 Define*, because they had much more text compared to cards used in Steps 1 and 3, where data were presented in a more illustrative way. Another problem arose when participants were supposed to define the location of VGs. The map became less readable and the boundaries between zones were blurred due to the extensive usage of shading layers and colors to map the issues and identify spatial zones (Figure 3).

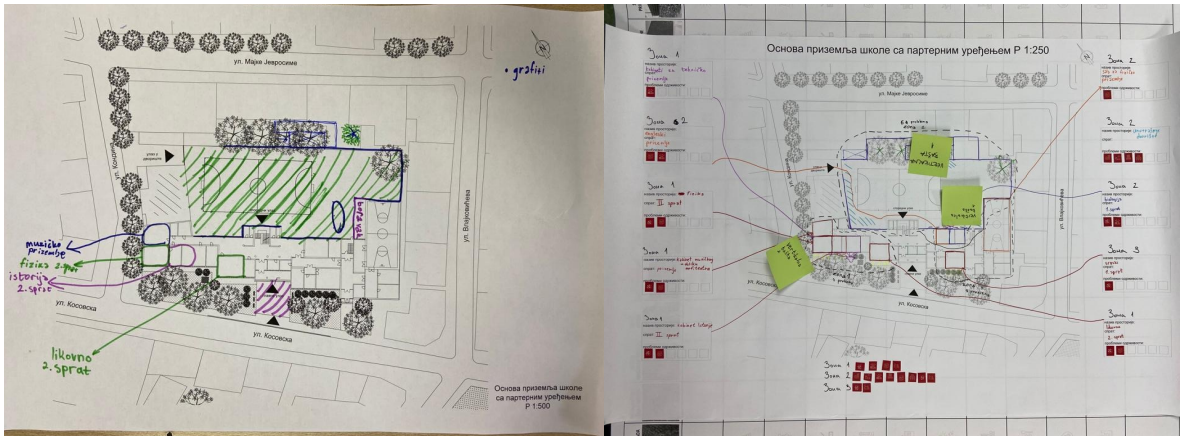


Figure 3: Results of the Step 2 Locate. Source: (Author 2024)

Teachers emphasized how demanding the preliminary procedure was. More specifically, they explained it as an extremely tedious and time-consuming procedure that involved them personally enclosing consent forms and project information letters to each student and parent involved. Moreover, the signed forms were delivered at the last minute since some of the children were used to forgetting to tell their parents about the project.

Another technical challenge was the lack of participants educated in architecture. The researcher was assigned several complex assignments that overlapped in time. It was demanding to moderate the project, guide participants through each step, act as an expert in architecture, search for process obstacles, respond to further inquiries from participants, and take notes. This allowed omission in the researcher's work. Teachers were also unable to take on specific tasks since they occasionally had to leave workshops to attend unplanned class events.

2.4 Evaluation of the VGs' co-design method - interviews as a tool with the greatest participation interest

When asked to interview other school community members to explore VGs' potential for formal, non-formal, and informal learning (Million et al., 2019), all students were enthusiastic and showed significant interest in the task. Many students found this co-design step to be the most engaging. This may be explained by the fact that the Step 5 Plan calls for the only "physical" activity in the entire VGs co-design process. Students were required to leave the classroom and interview appropriate members of the school community. Additionally, there was notable interest from the school community members interviewed, most of whom were teachers (50%). Students comprised 31% of the interviewees, primarily those involved in school sections or organizations, while the remaining 19% were school employees. A substantial majority (88%) expressed interest in the educational use of VGs, suggesting various ways to integrate VGs into the curriculum. Surprisingly, 63% indicated they would also use VGs for after-school activities and during holidays. However, as a procedural issue related to the conduction of the interviews, the researcher states an undefined duration for the task and an unspecified number of necessary interviews. Moreover, no analysis of collected data from the interviews was done by the participants, thus no reflection on the findings.

2.5 Evaluation of the VGs' co-design method – a sense of belonging and responsibility

The Step 5 Plan developed a wide range of recommendations, regardless of whether participants used their imagination, creativity, and wishes, or whether other school community members in interviews expressed their ideas for the use of VGs. Considering social issues such as safety, inclusion, health, participation, and education, most students developed a personal connection and responsibility to the VGs they have designed. Straightening their voices through group discussions, students suggested sustainable ways for their VGs to function in all three aspects – economic, ecological, and social. Teachers noted that a few months after the workshops concluded, some students frequently inquired about the construction timeline for their VGs. The primary challenge students

sought to address was ensuring the safety of the VGs, as they feared potential damage. They viewed the schoolyard space near the VGs as their own but also envisioned it as a shared space where others could equally enjoy the surroundings for relaxation between classes. Providing additional VGs furniture such as speakers for relaxing music during school breaks between classes, an information table with rules of VGs use, benches, and a soft rubber paving would, in their opinion, provide them child-friendly school environment,

> a place where children like to spend time and play, a place where their physical, social, and emotional development takes place (Nordström 2017, 151).

3.0 CONCLUSION AND SUGGESTIONS

One uncommon case of action research with a participatory approach conducted in a Serbian primary school involves the development of a BEE co-design method for VGs, incorporating topics of ESD. This five-step process calls at a large number of individuals in the school community who are interested in subjects that this interdisciplinary process covers. Beyond serving as an architectural tool for co-design, this method is a formal learning tool with potential as non-formal and informal. This VGs' co-design method was created as a BEE tool to address sustainability issues through a biology and technical education curriculum in primary school in Serbia, spanning 12 school classes in total. Given the challenge of curriculum changes, the same procedure can be implemented through after-school activities in various school sections, such as ecology, art, science, and other related subjects. Furthermore, if any of the intended steps have already been completed through other school-related activities, the design process may proceed more quickly. For instance, STE(A)M projects carried out in one school in Serbia during the 2022–2023 school year led to the identification of local ecological issues ("STEM – Project Report" 2023), thus allowing the method's adaptability through the exclusion of Step 1 *Identify*. Additionally, such a gamified process can act as an effective instrument for encouraging youngsters to express their needs through dialogue and group decision-making regarding sustainability and their school environment. Applied activities can also be seen as catalysts of change, empowering young generations to play a more active part in spatial and ecological changes, as well as a way of transferring gained knowledge to their parents.

Finally, this study proposes suggestions for enhancing the novel VGs co-design method. Suggestions are based on the evaluation of data collected through semi-structured group discussions after each step conducted with students, as well as individual reflections by teachers, architects, and one pedagogue after completing the process:

- More Outdoor Tasks: Incorporate field activities, such as observing potential locations for VGs.
- Sensory Engagement: Include tasks that encourage participants to engage their sense of touch and smell, such as providing samples of plants or creating miniature VGs mock-ups.
- Educational Aspects Extension: Introduce new steps in the design process to cover educational topics like water treatment, considering that the current process does not include selecting a VGs' irrigation system.
- Development of Evaluation Tool for Interview Data: Create and implement an evaluation tool to analyze data collected from interviews with other school members. This tool should provide a framework for the future educational use of VGs.
- Continued Engagement: Assign homework when workshops are not held consecutively to ensure students' continued engagement and retention of the topics covered during the design process.
- Integration of Technology: Consider incorporating technological devices such as cell phones or computers to enhance learning. This could involve students using these devices to access more images and information about VGs, thereby deepening their understanding of new concepts and VG features.
- Further Testing and Review: Conduct additional testing and reflection on the method by professionals such as researchers, architects, and educators in various urban areas across Serbia.
- Adaptation to Different Contexts: Develop recommendations for adapting the VGs co-design method to different educational contexts outside of Serbia.

All the proposed suggestions seek to refine and extend the VGs' co-design method, enhancing its effectiveness in addressing sustainability challenges and improving learning outcomes. Furthermore, the study highlights avenues for further research, including additional testing rounds and post-project evaluations to assess the method's potential long-term impacts and scalability. Finally, a detailed comparison is required to evaluate the extent to which the method aligns with and complements the existing curriculum in Serbia.

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Systems Thinking: A Methodological Approach for Understanding Urban Complexity

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ABSTRACT: The environmental, economic, and social changes in the last decades demand the readdressing of the city as an adaptable one defined through a network of interwoven relations rather than well-defined rigid structures. This intricacy forges the redefinition of accustomed design practices to manage the desired inclusive, adaptive, fluid, and responsive conditions of cities. However, incorporating these coexistences in defining urban conditions necessitates a multi-focal rendering of the associations and a speculative practice of a new methodological approach. Therefore, we need novel methodologies of research in the field of architecture. This paper will propose revisiting 'systems thinking' as a new methodology to research the pluralities, contradictions, degradations, and climatic challenges of contemporary cities. Rather than a top-down design approach, 'systems thinking' initiates a non-linear process by focusing on the relationships and interdependent variables. Therefore, embracing 'systems thinking' in the definition of contemporary cities can respond to the ever-changing conditions, which can alter the design practices and teaching-based research processes.

However, to envisage and structure a system that can respond to the pluralities, complexities, and contingencies of the ever-changing conditions, a deep reading of the city should be provided that can be produced, processed, or engaged in all phases of the design process. In this respect, experienced data avalanche and interaction with the large scale of bytes used for data-driven practices can be considered as a challenging transformation that proposes deep readings of cities and hence can be used in practicing a 'systems thinking' approach. This new method of engagement with data-driven practices cultivates an architectural transformation by sourcing, inspiring, and informing the architectural design processes for understanding the notion of resilient cities. The paper speculates on the potential of systems thinking initiated by data visualizations in producing deep readings and research on contemporary cities and its use as a methodological approach in architectural design education.

KEYWORDS: systems thinking, data visualization, architectural education

INTRODUCTION

Over the past few decades, cities have experienced significant physical changes due to environmental degradation, ecological destruction, and human-induced climate change. These changes have significantly impacted urban conditions and their representations, necessitating a rethinking of the city as a more complex, saturated, and open system. The contemporary urban environment, characterized by diverse interactions and spatial dynamics, can be seen as an ecosystem encompassing socioeconomic, biological, geographical, ecological, and experiential elements. At the juncture of these social, economic, ecological, geographical, and experiential crises, architecture as a discipline is expected to define resilient approaches for unprecedented urbanization, climatic degradation, and ever-accelerating technological advances and challenge the norms and expectations with an interdisciplinary perspective. (Easterling 2014)

In order to understand these redefined urban conditions, it is essential to adopt a holistic perspective that examines the extensive associations and relationships within urban environments. This necessitates reevaluating assumptions, strategies, and tactics across urban design, architecture, engineering, and politics. Today's Architectural research must incorporate a multi-faceted approach to capture the complex interactions integral to the economic, political, and ecological dynamics of 21st-century cities. Since architectural research cannot be separated from the current state of cities, addressing the intricate, unpredictable, and dynamic nature of contemporary urban conditions requires a series of zoom-in and zoom-out analyses. The proposed research methodology has the potential to shift between different scales in understanding the broader dynamics of the city. We can only develop a complex matrix capable of accommodating new networks, connections, and phenomena through such a comprehensive approach, thereby providing insights into the emerging conditions shaped by various agents, including human, non-human, international, intergovernmental, and non-governmental entities.

2.0 SYSTEMS THINKING AS A METHODOLOGICAL APPROACH FOR COMPLEXITY

This conscious approach that requires working with multiple perspectives and acknowledging the emergent conditions defined in line with various diverse agencies in research is hard to achieve, especially in undergraduate education in architecture departments. It is a fact that architects need new tools and methodologies to develop this kind of deep research on cities. To execute an experimental research process in architecture design studios, a novel methodology called 'systems thinking' is instrumentalized for two consecutive years. Systems thinking is an approach that considers the overall system together with other related systems and its discrete parts. As Peter

Senge discussed in detail, it is a terminology that belongs to the management field as the fifth discipline. He defines systems thinking as a framework for creating a learning organization where parts interact with each other and build complex systems. According to Peter Senge, (Senge 2006) systems thinking is

> a framework for seeing interrelationships rather than things, for seeing patterns rather than static snapshots. It is a set of general principles spanning fields as diverse as physical and social sciences, engineering, and management.

For Senge, 'systems thinking' as a discipline is instrumental for seeing wholes through, focusing on inter-relationships rather than things and patterns rather than static 'snapshots.' (Senge 2006) It defines a cohesive system where different parts, in different scales and with different properties are interrelated with each other to define a complex whole. Having these potentials, systems thinking can be acknowledged as a research and even design methodology for studying complex structures and understanding the dynamics of a system from different perspectives. Adapting this methodology in architectural research, especially to study contemporary urban conditions, can be regarded as a meaningful strategy for understanding and engaging with the rapidly changing and evolving cities.

Providing an in-depth understanding of a comprehensive approach to studying complex conditions, systems thinking necessitates the ability to represent and assess dynamic complexity, acknowledge feedback processes, identify relationships rather than outputs, and recognize nonlinearity and irregularity. (Sweeney & Sterman 2000) The common concern in these necessities recognizes a dynamic 'behavior that arises from the interaction of a system's agents over time' that leads to various levels of complexity. (Sweeney & Sterman 2000) Welcoming collaboration and input, systems thinking as a methodological approach aims to increase the delivery of complexity and hence focuses on defining a complex whole. The concept of 'wholeness' considers that a system comprises various other sub-systems, which consider the definition of a system. For example, according to Russell Ackoff, a system is not the sum of the behavior of its parts; it is a product of their interactions. (Ackoff 2015) This definition of wholeness as a system enables understanding complex organizations operating in a dynamic and interconnected way and hence focuses not on the discrete elements but their interaction. Aiming to zoom in and out to see different relations and interactions, the concept of wholeness in the systems thinking approach prioritizes the dynamics of the system rather than the outputs. Therefore, acknowledging the systems thinking approach allows focusing on the whole system with a holistic view and requires us to consider each action in the context of the broader systems in which it is embedded. (Cavaleri and Sterman 1997)

Another specific concern of systems thinking is the dynamism of the organization, which demands a specific emphasis on feedback loops rather than the linearity of the process and cause-and-effect relationships. Considering the effects of action not only on the discrete condition isolated from its broader context but also its influences and effects on other systems alters the way the system is envisaged. (Senge 2006) The conceptualization of the system as a 'whole' composed of various complex systems in different scales and compositions allows the redefinition of each sub-system concerning a change defined in another system. This continuous feedback loop within the system also embraces the concept of emergence, where the system's behavior cannot be predicted only with individual components.

Since urban and architectural development strategies are expected to deal with diversity, manage technological challenges, encourage sustainable development, react to climate change, environmental degradation, and ecological destruction, etc., urban and architectural research and development strategies are expected to define a holistic approach that embraces tolerance and complexity. Embracing systems thinking in the reading, designing, and structuring of contemporary urban conditions may foster the architect in dealing with the pluralities, contradictions, degradations, complexities, and challenges of 21st-century cities. By adopting this methodology, architectural research can consider the broader and long-term implications, focus on interrelationships rather than cause-and-effect relationships, and provide a multi-focal rendering of relations, which defines a holistic approach to the design problem.

However, the structure and the concept of 'systems-thinking' necessitate an in-depth, interdisciplinary approach that recognizes the change as constant (Weisz 2018). To acquire, interpret, and use data about the city in constant transformation, the research may incorporate qualitative and quantitative data, which has become available with emerging technological developments. Especially data visualizations, which allow different and diverse information and data to be displayed simultaneously, can be used to associate with systems thinking methodology. When considered as a new challenge for the systems-thinking approach, these multilayered and multidimensional representations of complex data can map the ever-changing relations and ever-expanding data of the city with all its components and alter how we understand, define, and visualize the cities.

3.0 SYSTEMS THINKING IN ARCHITECTURAL DESIGN EDUCATION

This approach of producing a deeper analysis of the city in various scales and perspectives, where several systems interact to define a complex whole, provides advantages for embracing complexity in architectural research. With this framework, the paper presents a selection of student works produced in an undergraduate architectural design studio at TED University, Department of Architecture in Ankara, Turkey. The examples to be discussed aim to reveal how an approach of 'systems thinking' often associated with the management field has been adapted in architectural research as a method for reading and discussing the city. The article aims to uncover the potential of this methodology by sharing the outcomes of a survey conducted with the students who went through this experience, in addition to the discussion on examples produced in the design studio. As can be seen in the detailed

discussion of the examples, the systems thinking approach, which is usually operationalized in the first semester of the 4th grade, expects students to develop a series of readings and interpretations about the whole city based on the region they examine rather than focusing only on a particular site within the city. Therefore, the assigned areas for each semester require particular inquiry, which necessitates solutions and design approaches at an urban scale rather than an architectural scale and generally consists of problematic areas within the city.

Two major port cities in different geographies were studied in two years: Beirut in Lebanon and Samsun, another significant port city in Turkey. Even though the cities are different, the studio's main objective remained constant. It was explained as discovering the spatial, material, and experiential dispositions along the encounters of water with land/city and developing adaptive, solitary, and resilient strategies for the particular urban context. Most of the examples to be discussed here, which are named ‘operative mappings’ in the studio, benefited from the research conducted in the first 3-5 weeks of the design studio practices. All the student groups focus on a different aspect in structuring the basis of their research. However, the main aspect common in all examples lies in their attempt to develop distinct tactics for studying complex urban conditions and utilize systems thinking to cope with the discovered pluralities and network of relations. Incorporating systems thinking as an architectural research methodology and cooperating with data visualization strategies provided valuable inputs to the studio to discuss complex problems that cities face today, generate ideas about rapidly changing cities, and ensure resilient futures for the cities.

Two cities selected for research, Beirut and Samsun, provided very productive examples to study, as both cities face an urban collapse on many scales. For Beirut, problems related to the economy, urban management, transportation, lack of access to public and green spaces, and climatic risks are just a few examples of the problems that await solutions with larger-scale interventions and sets of integrated urban strategies. The Beirut Port explosion on August 4th can be regarded as a natural consequence of this downfall at many stages. The blast created a ground zero condition at the port area, literally hallowing the land and urbanscape of the waterfront urban edge. Any attempt to understand the particularities of this urban land of Beirut and the present conditions before and after the blast requires a deeper analysis of the many aspects of the city on a larger scale. The multicultural structure of the city, its historical significance, and its position within the region also play an important role in understanding and reclaiming the city's urban qualities and edge.

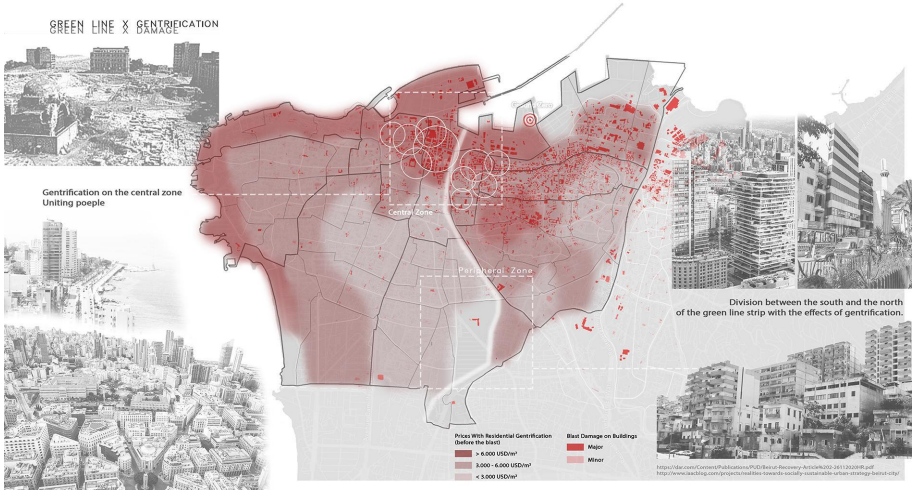


Figure 1: Demarcations of Green Line and other forces that affect the emergence of new urban zones. Source: (Emine Koç, Melisa Yılmaz, Nisa Gülin Özkan, Zeynep Köksoy 2022)

Perhaps Beirut's most important urban element, the *Green Line,* is an urban entity that triggers different relationships in every period of the city, regionally, sociologically, and historically. However, it is not an inactive urban formation or a single line that demarcates two distinct parts within the city, but an element of compromise and change, characteristic of which is unique to the city of Beirut. Regarding its different roles and pluralities, the visualization of the data tries to unfold the extent of associations and web of relations that can reveal the more significant dynamics of the city. As seen in Figure 1, the research collected and combined the data acquired from the Beirut Recovery Map (2024) to reveal the damaged buildings' information after the blast and the changes in the rental prices before and after the blast. The mapping of the information exposes demarcations of Green Line and other forces that affect the emergence of urban zones within the city, which are different from the accustomed typology of the city. These zones are divided into two parts, as displayed below. (Figure 1) The idea generated the zones of differentiation and how Beirut altered its morphology after experiencing a catastrophic event. Furthermore, it is a way to interpret different layers of the city and the impact of these layers on each other, all of which can be considered as design data that initiates the design processes.

Redefining the water edge in urban systems is another type of research where dynamic data, like the constant change in the edge conditions of the coastline in Beirut, were analyzed and visualized. The main idea in the research aspired from the intention to utilize variable and dynamic data such as climatic changes and tidal cycles as design input instead of more static geographic data. Non-human agencies, like the changes in the shoreline through the movements of the sea, when overlapped with more static geographic qualities or human interventions as the main subjects of research, initiated a holistic design approach to the definition of the coastal edge in a city, which is surrounded by sea on three sides as seen in Figure 2. The systems thinking approach in the case of this research

provided a ground for a holistic approach that is obtained from constantly changing data and turned into a problem-solving tool for the city's future scenarios related to the sea and the shore. The notion of boundary and its architectural interpretations were put under inspection to research interdependent variables.

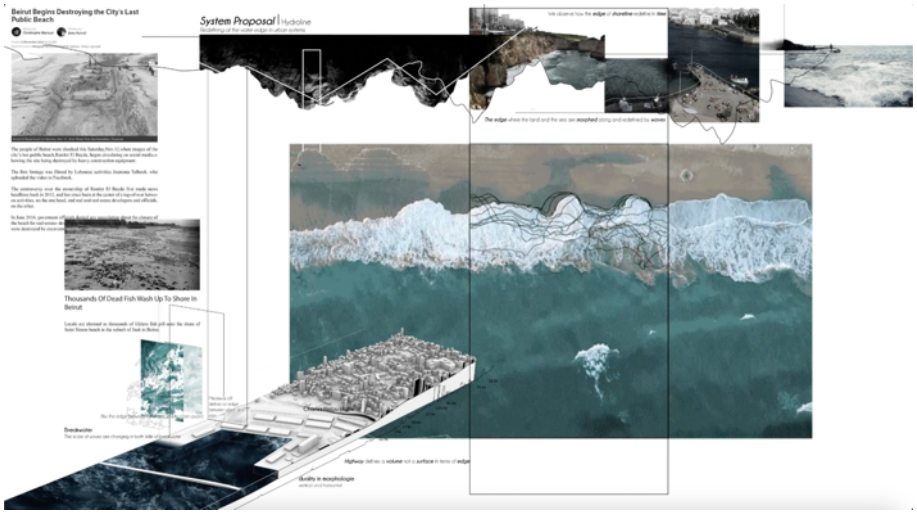


Figure 2: Redefining the water edge. Source: (Cansu Sivrikaya, Sema Akbacakoğlu, Gizem Simay Engin, Almina Yakut 2022)

In trying to map the relations between the coastline and the river in Beirut, another project recovered the data related to *drilling private wells* everywhere within the city. With these legal and illegal wells, the underground water fabric of the city of Beirut has been entirely changed by human hands, and the water network of the city has taken on a completely different character. These private wells are discovered to induce a marked rise in seawater infiltration, as the amount of extracted groundwater gradually exceeded the amount of natural recharge water. (Acra, Milki, Karahagopian, Raffoul 1997) Visualization of this data provides a layout that maps the unseen, unrecognized, yet vital aspects of urban life. The visualization of this relatively invisible data, just as conventional base maps that show geographic information, is utilized to lead to the emergence of different design systems related to future water uses of the city. (Figure 3) The data is visualized through overlapping different layers of information, the wells, the riverbeds, the morphology of streets, etc, as discrete but interactive systems working with and affecting one another.

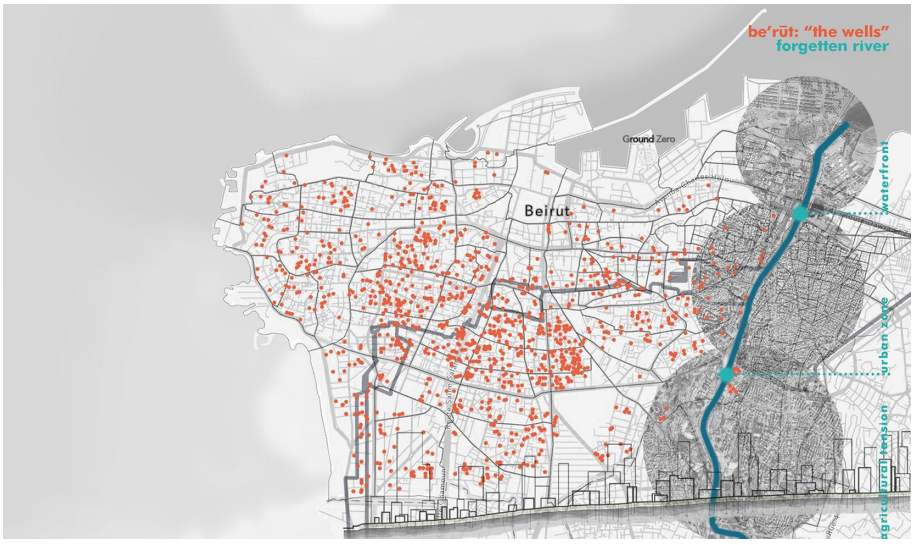


Figure 3: Drilling of private wells throughout the city. Source: (İlayda İlaslan, Mine Gülsün Kahveci, Seher Begüm Boztepe, Semiha Nur Korkmaz 2022)

In another example, pollution was mapped as an environmental and climatic problem in Beirut. Pollution is one of the most important problems in many cities today, and each city is expected to develop novel strategies to tackle it. Pollution threatens cities in many aspects, ranging from water to air pollution and other small-scale pollution like streets, rivers, etc. Beirut is no exception in its struggle with pollution at many scales that constantly interact. Research on pollution levels within the city should inevitably consider its causes and results and the reciprocity between different types of pollution. In the research displayed in Figure 4, the map integrates different information on pollution acquired from municipal documents and other resources. Different layers of information directly related to or affecting the general level of pollution in the city, like the pollution levels in the water, the intensity of NO2 by traffic, pollution caused by trash, distribution of pollution by wind, and the number of sea outfalls, creates a composite map, where different territories of pollution accumulation can be observed and studied. (Figure 4)



Figure 4: Layers of Pollution in Beirut. Source: (Doruk Özkoç, Ardacan Özvanlıgil, Emre Şimşek, Yıldız Cemaloğlu 2022)

Regardless of their subject of analysis, all the examples discussed here try to unfold how social, economic, and often political approaches transform the city and how these features, invisible or visible problems, and potentials are interrelated, thus making the unknown urban networks more comprehensible. This methodology can be argued to constitute one of the promising methods for architecture's relation to the unknown and imperceptible. In this methodology, data visualizations are argued to be one of the most indispensable tools for reading today's cities, and they work in an integrated manner with systems thinking, as they mutually support one another. In the following semester, the utilization of systems thinking allowed multiple issues to be considered simultaneously, similar to the examples discussed in the case of Beirut.

The city of Samsun, which is also an industrial harbor on the northern coast of Turkey, copes with the consequences of urban challenges outlined in the last decades, which alter its social, geopolitical, environmental, and architectural conditions. Considered a transfer and industrial node in the northern region, Samsun has a transportation network where Anatolia is connected to the black sea region through various means. Governing the national and international trade routes for years, the city has also been promoted as an industrial and agricultural hub, which augmented its geopolitical and geomorphological stance in the region. However, environmental degradation, urban destruction, and industrial policies have altered the definition of the urban conditions of the city and its definition noticeably in the last decades.

One particular example in this semester provided comprehensive research not limited to the city of Samsun but developed from an analysis on a much broader scale. Named as *Water Formation Library,* it can be regarded as a reading that defines the relationship of the city of Samsun with water through the analysis of the water textures of different cities and reveals the map of potential texture formations carried by the water movements. The project aims to retreat the Mert stream in Samsun, which has lost its quality as a wetland due to uncontrolled uses, and to restore its potential for irrigation as part of a larger-scale water network. To propose a system for this new network, mapping the existing water patterns throughout many cities and comparing them to one another enables the building of a comprehensive library, which can direct the design in achieving various tactics of water manageability. The acquired information and its collective mapping to be perceived together rather than separately inevitably pave the way for the formation of different associations of data that are not perceivable when analyzed independently. (Figure 5)

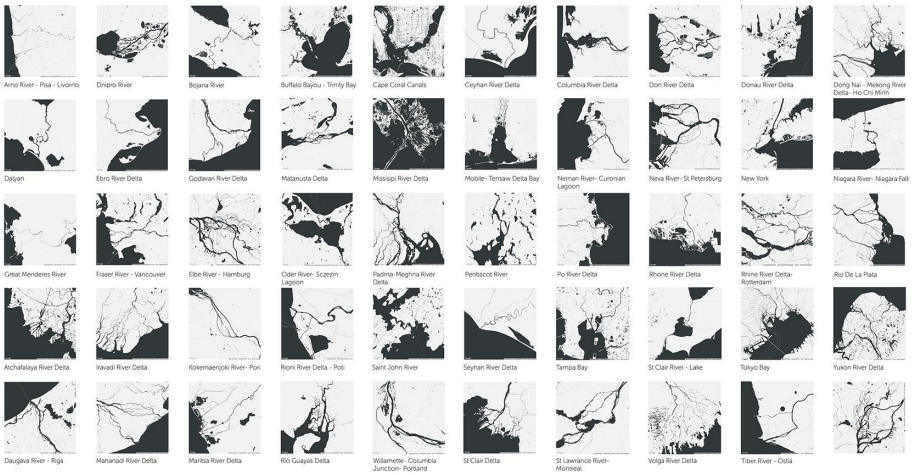


Figure 5: A library of water-land relations. Source: (Bartu Aydınlı, İlayda Ülgen, Zeynep Süner 2023)

On the other hand, the project called *The Night Drift* tries to map the life between the buildings in Samsun in an area that includes the port and the idle spaces surrounding the area. The port of Samsun stands out as an urban

element that affects the use of the city's coastal area and its relationship with the sea with an impact that covers a larger circle than its actual position within the city. Mapping out the human activity patterns approaching the port area night and day reveals a reading of the voids created by architectural structures rather than the structures that make up the city. It is the visual documentation of what is not visually evident or easily accessible at first glance. The project tried to establish a framework for discovering the interrelationships between urban entities, making visible the complex network of human flow together with connected and disparate zones of interaction (Gehl 2001). Its power in triggering a systems thinking lies in the way it overlaps different activity patterns to reveal the legibility of the relationships between uncanny spaces, crowded spaces, or spaces of attraction within the city that we do not perceive in our daily life, and most importantly the relationship patterns that bring these differentiations and contradictions into existence. The design process builds on this rather unconventional data set that can trigger new understandings for embracing complexity in understanding urban dynamics. Uncovering the patterns that lead to the emergence of certain urban conditions is regarded in the studio as a strategy for deep reading that can reveal a systematic approach to understanding the city. (Figure 5)

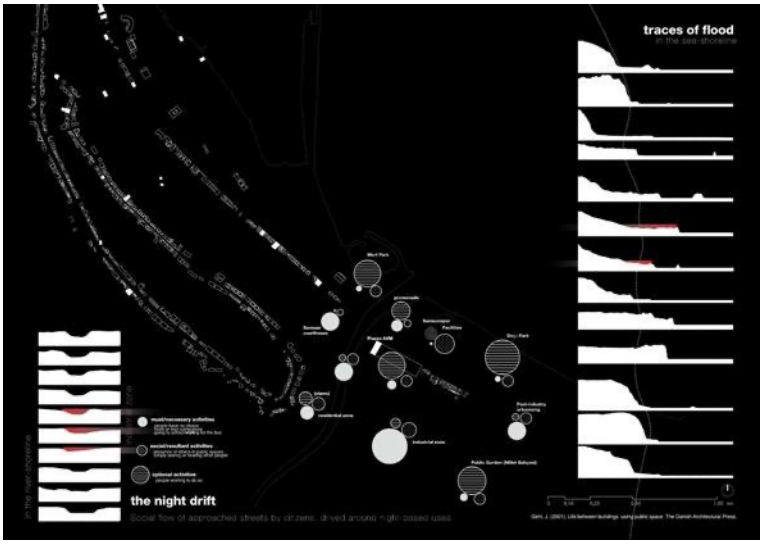


Figure 6: Data visualization displays the working hours of social spaces (café/restaurant, commercial facilities, social spaces etc.) and the related social flow of citizens in the city (Samsun). Source: (Başak Ünver, Betül İlayda Yılmaz, Zehra Dağıstan 2023)

The selected examples emphasize the interrelations in the city and discover the complex relations where various layers of data were overlapped and reinterpreted. In the studio process, the data visualizations produced also create another data set that contributes to the learning environment of the studio. Each visualization provides a different perspective on the city's urban conditions and initiates the reading of visible and invisible conditions. Although the paper includes selected examples from studio productions, the visual palette of data sets defines an explorative ground for architectural research and design. (Figure 7)

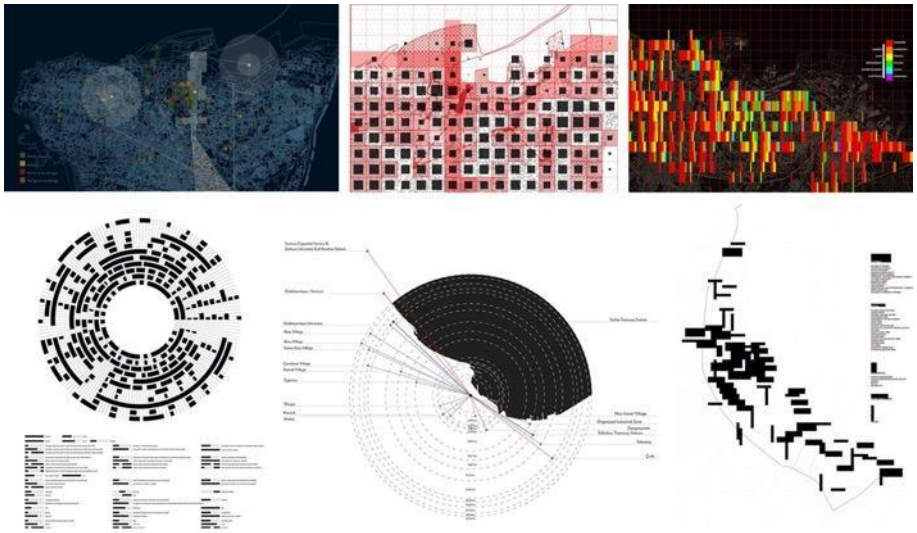


Figure 7: Data visualizations of the urban data were selected from two different studio processes. Source: (TED University 4th year studio works 2022-2023)

4.0 SURVEY ON SYSTEMS THINKING

The mentioned architectural research carried out by embracing systems thinking in architectural design education can be analyzed from various perspectives, specifically through data visualization. The increased exposure to continuous and massive data input from various sources alters the definition of a system and, hence, the consideration of systems thinking as a methodology. Therefore, an anonymous survey has been administered to a group of students to deepen the outputs and reflections of the aforementioned studies. The main concern of the survey was to understand the aftereffects of embracing systems thinking as a methodology in architectural design education and to reflect on the relationship between systems thinking, data visualization, and urban conditions. In this framework, the survey was applied to 25 students who have experienced the architectural design studio with systems thinking emphasis in the 4th grade. The questions can be categorized into five main groups, which are experiencing systems thinking as a design methodology, its advantages and disadvantages in the design process, integration of data visualization into the design process, using systems thinking in reading the information gathered in different scales (especially in urban scale) and the discrepancies between a systems thinking approach and the conventional architectural design approach. (Figure 8)

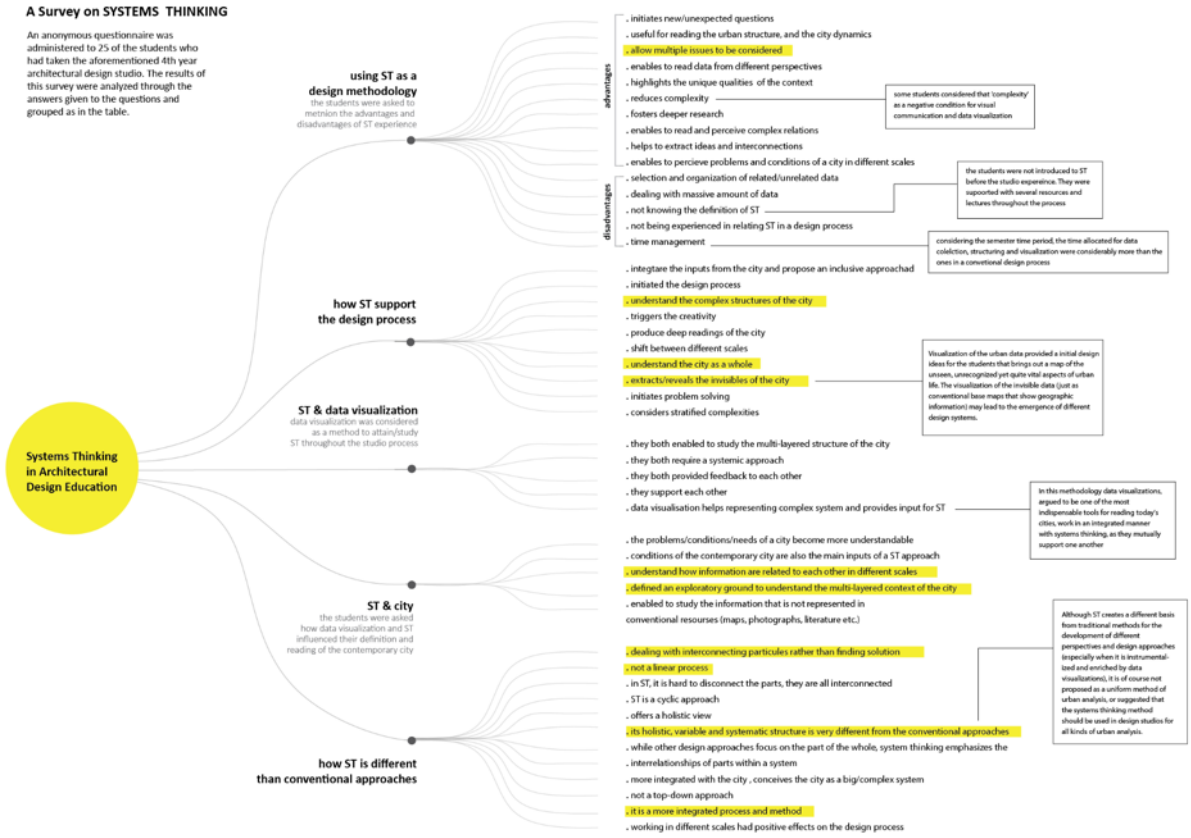


Figure 8: The outputs of the survey on systems thinking in architectural design education. Source: (Başak Uçar23)

According to the survey outputs, the students indicated that the definition of the design process through the systems thinking approach enabled them to have a holistic view of the design problem, including various perspectives/data/inputs from the urban scale. The ability to include multiple issues, organizations and data sets was considered a challenging design task since it initiated the consideration of '*unknown*' or '*invisible*' conditions of the city. Besides the conventional materials used for analyzing the city, such as maps, photographs, drawings, etc., systems thinking was also mentioned to have a positive impact as it revealed the unique qualities of the city and opened up new grounds for design exploration.

Another important output received from the survey was that the students were challenged by dealing with the complexity of the city and explored the potential of data visualization in defining systems thinking. They also noted the interactions between systems thinking and data visualization processes and underlined how they both supported each other. This can be considered a positive output of integrating data visualization methods into architectural research through integrating systems thinking in architectural design education. Compared to conventional architectural design education experiences, the students also indicated the positive implications of dealing with the complexity and massiveness of data inputs. This remark is a feedback of structuring systems thinking methodology through data visualization in large-scale architectural design problems.

Students also noted the difficulties of understanding the definition, potential, and requirements of systems thinking as a research and design methodology. Although systems thinking is studied in other disciplines and has deep literature, its acknowledgment in architecture -primarily through data visualization- can be considered a novel approach. Therefore, the students lack the necessary theoretical and technical background for systems thinking. The competence of the students in data visualization techniques and dealing with massive amounts of qualitative

and quantitative data can also be considered as a deficiency in the application of systems thinking since inadequacy of time management and data structuring were mentioned in the survey by the students as the disadvantages of the methodology.

With all these advantages and disadvantages, systems thinking in architectural design education and its research through data visualization tools can be considered a novel approach and, hence, be acknowledged as a methodology for studying complexity. Although the survey reveals the potential of this approach in the architectural education process and the need for competency in dealing with complexity, its capacity as a methodology in architectural research is also significant in producing deep readings of contemporary cities.

CONCLUSION

The research process discussed aimed to test an experimental approach that challenges traditional urban research methodologies, as conventional tools and resources are inadequate for understanding the complexity of today's cities. These exercises aim not to propose a uniform methodology of urban analysis or to suggest that systems thinking should be universally applied in design studios for all types of urban research and design. Given that the examples analyzed and discussed come from undergraduate studies, they do not have a deeply developed research background. However, most of the research within the design studios benefited from the systems thinking approach as it provided a fertile ground for discussion on how research can benefit from working with multiple data sets and inputs. Although some research failed to respond to the complexity of systems thinking and data visualizations, they can still be considered preliminary attempts in adapting this method to the design studio. As the article argues, systems thinking provides architectural research with new ways to engage with urban complexities. It offers more open-ended, flexible research and design processes than conventional methods. In the words of Senge, (Senge 06)

> Systems thinking is a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively.

Therefore, it can also be regarded as a method suitable for responding to the shifting conditions of the city and its components, including human and non-human aspects, and understanding the network of relations that structure the very essence of the contemporary city, with all its *unknown* climatic, environmental, political and social problems. Looking ahead, ensuring the resilience of cities is likely a primary focus for architecture and architectural research. Expanding the scope of architectural research and integrating diverse data and inputs are essential for developing ecological approaches and fostering a more sustainable future. In this context, it is clear that systems thinking, enhanced by data visualizations, plays a crucial role in architectural education and research processes.

ACKNOWLEDGEMENTS

These exercise series are the result of experimental design processes developed in TEDU Faculty of Architecture, with the contributions of many partners. We would like to thank all the colleagues, who provided important input and feedback to the intellectual development of this assignment series and their execution in design studios in different years. In this respect, Alper Kiremitçi, Çağrım Koçer, Eser Köken İşleyici, Esatcan Coşkun, Evren Başbuğ, M. Ziya İmren, Onur Özkoç, Onur Yüncü, Utku Coşkuner provided valuable contribution as studio instructors. An initial version of the ongoing research was presented in Turkish at MITA Mimari Tasarım Ulusal Sempozyumu IV Conference, organized by Özyeğin University in İstanbul, in April 2024.

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Building a Lab: Constructing Realities

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ABSTRACT: Laboratories, as enclosed architectural-material spaces, are defined by clear physical boundaries. However, the knowledge produced within them is universal, transferable, and subject to transformation. This paradox is reinforced by models and apparatuses, which not only facilitate the expansion of knowledge but also enable the translation of the given world into data, or conversely, the materialization of data into physical reality. Laboratories possess an inherent capacity for knowledge production, allowing them to mediate between diverse agents, operating across multiple scales, through the use of models. The spatiality of the laboratory extends beyond its physical confines, defining and applying models within varied epistemic boundaries—in vitro, in vivo, in papyro, in silico, among others. Within this framework, the laboratory constructs a "code-space," a self-referential domain in which knowledge is continuously generated and reconfigured through material processes. Moreover, the integration of apparatuses not only facilitates the implementation of models but also shapes the way the world is observed and interpreted within the laboratory setting. These intertwined mechanisms transcend mere experimentation, establishing a dynamic interplay that can only be realized within the laboratory environment. However, when applied to architecture, the notion of the "laboratory" does not conform to this exact paradigm.

Architectural researchers are increasingly formulating new methodological frameworks by engaging with material relationships embedded within previously overlooked disciplinary silos. These emergent spaces within architectural practice seek to situate themselves within broader debates concerning future scenarios and the ongoing discourse between theory and practice. At this juncture, despite foundational critiques of scientific research and knowledge production, this study interrogates why architecture, as a discipline, has adopted the "laboratory" model under its own name. Through a comparative reading, the research examines the emergence of architectural laboratories as a practice in relation to the critical junctures that have shaped the evolution of scientific laboratories. Beginning with the historical precedent of Frederick Kiesler's *Biotechnology and Correlation Laboratory*, established in 1946, this analysis traces the underlying motivations for the resurgence of the laboratory phenomenon in the 21st century.

KEYWORDS: architectural laboratories, practice, experimental architecture, agents in lab

INTRODUCTION

A laboratory is a generator attempting to decipher the code of life and sharing it as an extension of the scientific language, both in the academic and architectural fields. These generators experiment and investigate through models the potential irreversibility of the damage caused to the planet economically, politically, and socially by human-centered created relationships in recent years. The scientific stage diagnosing the crisis also questions the possibilities of alternative relationships by reconnecting with the agents who cause irreversible damage to the planet, engaging in complex relationships, and being ignored. Scientific research conducted in the laboratory reveals both the problem and potential solutions.

To address the global crisis, interdisciplinary research groups are devising innovative strategies by integrating previously neglected material and immaterial relationships that have long been confined within isolated disciplinary borders. Knowledge is no longer perceived as an enigmatic byproduct of a closed research process; instead, there is a growing consensus that the convergence of social and positive sciences is essential for a comprehensive understanding of contemporary challenges (Rheinberger 2001). In the 21st century, architectural practice finds itself at the intersection of debates concerning emergent future scenarios and the enduring dialogue between theory and practice. Concurrently, evolving perspectives in critical theory, combined with the adoption of avant-garde methodologies that harness next-generation tools, are guiding architectural practice into transformative new spaces—such as laboratories and workshops—which, in turn, provoke a profound re-evaluation of the traditional subject-object hierarchy.

Collaborations aim to respond to a global crisis have begun developing new action plans by considering material relationships embedded in isolated research of disciplines that were previously ignored. Architecture's practice is in search of its place in debates that involve future scenarios and the ongoing discourse between theory and practice. On one hand, emerging critical-theoretical frameworks and the pursuit of innovative modes of fabrication enabled by next-generation tools are drawing architectural practice into novel domains—such as laboratories and workshops. On the other hand, the imperative for a reimagined spatial framework, within which architecture can fully realize its practice, is driven by the need to proliferate experimental models that rigorously test speculative ideas. This approach not only enriches the field with diverse methodologies but also reconfigures the traditional subject-object hierarchy, effectively rendering all agents as nomadic participants in a constantly evolving discourse (Latour and Woolgar 2013).

Post-theory in architecture,—whether expressed through post-humanist perspectives or new materialist approaches—assumes the critical task of reinvigorating the connective and organizing frameworks of the discipline. Concurrently, it seeks to transform architectural practice by harnessing current technologies, thereby circumventing the inertia of traditional theory, and by integrating dynamic agents that effect change: agents that generate distinctions, engage in experimental practices, forge unique connections with materiality, produce modelable and testable prototypes, incorporate non-human participants, and articulate alternative trajectories of action through emergent languages (coding). Michael Speaks underscores that post-theoretical architectural practices find expression in creative spaces such as workshops, where speculative production is realized via the "knowledge table method" through rigorous testing and prototyping (Speaks 2005). He contends that the act of making arises from the design of knowledge—or "design intelligence"—achieved by decoupling design from conventional theoretical constraints, with "thinking by doing" emerging as a natural consequence (Speaks 2005).

Despite the contradictions, architecture's activity area giving the name "lab" to a practice that prioritizes making with technology, moving away from theory, harbors inconsistencies. This is because the criticisms of scientific knowledge production systems, which create new relationships between humans and matter at the climatic crisis center, share a common ground with new materialist and post-human theorists, who are based on problems such as the complete separation of human and subject from matter and research. On the other hand, the models encompassed by all active players in the laboratory defend that the reality presented in the laboratory is the product of both an experimental and self-affirming mechanism (Rheinberger 2001). While the experimental nature in the laboratory serves as a practice that produces differences, scientific knowledge ensures that the knowledge produced is valuable by reaching the same result under all conditions.

At this point, despite fundamental criticisms of scientific research and knowledge production, the research questions why the discipline of architecture has adopted a "making" practice under this name. To understand this, a comparative reading will be made between the emergence of architectural laboratories as a practice and the breaking points of scientific laboratories, starting from the historical context of the first reasons for the emergence of the "Biotechnology and Correlation Laboratory" (1946) founded by Frederick Kiesler. This comparison will question the motivations for the re-emergence of the laboratory phenomenon in the 21st century. And the inquiry will be conducted in two stages. Firstly, the purposes, problems posed, solutions, and research scales of the laboratories opened in academies in the 21st century will be examined.

1.0 PRACTICE

1.1 Problematizing the architectural practice and search for a new practice

After 2000's, architecture define its position between practice and theory. The mere referencing of the built environment by theory, coupled with the practice carving out its own space through technological interfaces and tools without relying on theory, leads to the need for architecture to establish a new connection in the stages of thinking, teaching, and implementing. Contemplating matter beyond its passive structure allows for the rearrangement of agents, but it also imposes the necessity of critically examining established connections. Announcing the death of theory, as Jonathan Culler pointed out, is more about determining how the discursive aligns with the practical (Culler 1997). Or, as Helene Frichot questions when the end of theory is announced, it is about being able to answer what architecture's role is (Frichot 2009).

Emerging critical theory that challenges traditional architectural paradigms fuels an ideological intensification, inspiring individual perspectives and forging a discourse centered on practice while embracing new technologies. This architectural discourse promotes a post-theoretical narrative in which theory—synonymous with an excess of knowledge—fails to incite practice, thereby necessitating a reevaluation of theory from an alternative vantage point. Jane Rendell portrays both the artist and art as manifestations of an "idea machine," where the idea itself constitutes the act of production, and thought is in perpetual transition into design (Rendell 2003). In this framework, the motivations and practices of the artist converge into a unified whole. However, such fluidity between theory and practice finds little equivalent in the realm of architecture. According to Rendell, architecture should, much like contemporary art, position itself at the intersection of thought and practice (Rendell 2003). Practitioners who engage with material relationships—whether as artists or architects—must develop methodologies that communicate directly with their material. In assuming this active stance, the practice of establishing relationships paves the way for innovative connections. Moreover, Rendell underscores the significance of action as articulated in Buchanan's abstract machine, contending that this conceptual framework facilitates an assemblage generated through the dynamic exchange of relationships, thereby opening avenues to new interactions (Rendell 2003).

In a new relationship, one can become a transformative agent by revealing who they are and how they are. Rather than the closure of a theory text by someone who knows everything, Rendell suggests writing and doing to articulate the unique relationships of the agent (Rendell 2003). This way, both writing and practice can work together. Writing as theory may not be enough individually to question or perform active production. Helene Frichot, while discussing the death of theory, criticizes the role of the theorist (Frichot 2009). The theorist has a perspective that looks down on everything and everyone. Such an attitude keeps the theorist away from the magnificence of architecture. It does not allow them to see established relationships and form similar ones. To recreate relationships, one must be active. Or simply doing cannot find solutions for today's crises. Rendell argues that here, the binding architect needs a standpoint (Rendell 2005). She draws attention to the need for a positioning that can respond to situated knowledge in Haraway, Jane Flax's standpoint theory, or Elsbeth Propyn's locality. Here, she provides the answer to what architecture actually does: architecture is a binding agent that "thinks between" matter and subject and "thinks as if

in between." The architect must determine how to position themselves with their object based on their (own) experience.

1.2 Re-connecting to earth

In the 21st century, architects, artists, or scientists have recognized the necessity of transitioning to an action plan that establishes active connections and is not limited by the narrow application of theory. However, the challenge arises here regarding how different forms of connection can be articulated, aside from the unique practice suggested by Rendell through writing. Feminist discourse, by juxtaposing disciplines in different situations and proposing dynamic connection methods, challenges accepted relationalities, and we, as agents, are still attempting to (re)identify with objects and matter. Referencing various philosophies, such as Bruno Latour's Actor-Network Theory (ANT) (Latour 1996) and Graham Harman's object-oriented ontology, which see existing connections and explore possibilities for adding or increasing these connections, we move away from forms of connection like correlation that read objects solely through humans. Thinkers like Latour and Michel Serres (Serres 2013) discuss a more active objectification situation through already established connections. The reciprocal dynamic between relationships and objects is boundless, affirming that emergent social bonds continuously engender novel artifacts in recurring cycles. For Bernard Stiegler, this phenomenon epitomizes externalization (Stiegler 1998). Humans engage with their surroundings through apparatuses, transmuting the inorganic and inanimate into organized matter.

While creating unity in social disciplines is possible through these theories, we face challenges in responding to the more complex relationships between agents in fields like art and architecture. However, architects/architecture, as binders establishing connections, have some components that need to be re-related. Firstly, how matter is physically addressed, organized, and how these forms of connection are incorporated into the field of architecture. The climate crisis requires a new action in disrupted material cycles caused by human-disturbed matter. Discussing the above-mentioned forms of connection in architecture becomes inevitable when examining existing relationships, especially those related to waste in the built environment, which remains in nature for years or cannot be recycled. In order to apprehend such intricately interwoven phenomena, we must adopt novel tactical approaches; Karen Barad's agential cut creates an active position, or, proposing a way of making against an attitude that homogenizes connection with matter, neglecting previously established complex forms of connection, especially in art and architecture (Barad 2007).

To develop a practice in which the creative agent may simultaneously embody both critical insight and generative capacity… Like the chain reaction produced in Peter Fischli and David Weiss's "The Way Things Go" work. The connector -or artist/architect- needs to transform into a series of actions, careful but chaotic, that they do not fully control or orchestrate, much like the chain reaction in the mentioned artwork. Or, imagining a making method where the process and material object are not dominated by the master, as seen in the exhibition "Suddenly This Overview," where sculptures symbolizing everyday objects from unbaked ceramics wait to be re-modeled, creating a geography that generates possibilities. The possibilities here are as powerful as the ope"-ended nature of a map. Thinking of architecture as a mechanism that considers the physical and chemical processes of matter, engages objects in a non-autonomous interaction without human intervention, is to envision a practice that does not dominate but orchestrates.

Architecture establishes active connections. Questions such as the positioning of the architect, complex relationships with matter, and the future of architecture bring forth significant inquiries, sparking new explorations in practice. Following the Kiesler Laboratory, we observe the continued motivation for laboratories to serve as spaces in cybernetic studies and those referencing organic elements, such as the Buckminster Fuller workshop. However, especially in the 2000s, numerous research-oriented laboratories are being established in universities. These laboratories are driven by their own desire for existence or the goals of the institution to which they are affiliated. In line with these goals, they conduct design research. These laboratories differ somewhat from field or material-centered testing laboratories where durability tests are performed. They represent new spaces where the design process invites other disciplines and new technologies.

1.3. Responses of architectural practice to scientific expansions on vitality

The association of architecture as a practice with the term "laboratory" began in the early 20th century with Frederick Kiesler. The Biotechnology and Correlation Laboratory, established by Kiesler at Columbia University in 1946, served as a unit where the externalizable reality of architecture was examined and researched. In Kiesler's laboratory, the body (perceiving and designing) was dissected both cognitively and physically in an attempt to expose its parts. For Kiesler, architecture is a way of connecting to the world; it brings agents in relationships to a neutral level as small as the cellular scale and attempts to both separate and reunite them in this created space on a physical-biological-psychological level (Phillips 2017). Kiesler's exploration, in its consideration of the relationships established through the body's interaction with the external environment, offers an early architectural response to a post-human perspective. However, within the correlation framework, it diverges from contemporary post-human debates by comparing humans to other objects or technologies. The effort to redraw the boundary between the living and non-living, the utilization of epistemological outputs produced in the laboratory as traces in cybernetic studies by architects, finds its place in the architectural practice of today and in post-human and new materialism thinking (Phillips 2017).

Towards the end of the 19th century, the laboratory's construction of scientific knowledge can be traced back to architectural thinking. References to elements of structures such as buildings and walls, the use of tools that allow the exploration and experimentation of a different scale of thought, such as models, have been employed. The implicit cross-referencing of structuralism by the laboratory, its methods, the closed nature of the experiment, and the way it creates and declares the "other" all influence every field, including architecture. After the 1960s,

discoveries in genetic studies, such as the nature-human relationship, the hierarchy of the other in a vitality classification reduced to codes, and the ability of the living to reproduce spontaneously, have influenced many disciplines as well. Particularly, creative fields have incorporated these scientific facts into their sociological, political, or technological practices, and references to them can be directly observed in representations and productions. Architects also frequently refer to the excitement they feel about the autonomous knowledge-generating capacity of the biology laboratory, describing practices that move towards spontaneity in the entropy/negentropy duality. Firstly Kiesler Laboratory, then the projects of Cedric Price Fun Palace in collaboration with Joan Littlewood (Littlewood 1964), Buckminster Fuller's biology-inspired structures, and Francois Roche's avatar-spaces…Again, 20th century, experiments in biology and physics laboratories mystified the laboratory itself in terms of the distinction between the living and non-living, matter, and time.

1.4. The transient boundaries based on the 20th century of laboratory practice and architectural practice

The laboratory, in the experiments of relativity from the early 20th century onwards, found itself in the position of having to explain the relationship between the object and the subject after the controversial position of the observer in the experiment. The positioning of the experimenter and the observer is in the shadow of the emergence of knowledge. The process that began with the relativity experiments has somewhat been illuminated towards the 21st century with the paradigm shift of Kuhn, the criticisms of science philosophers such as Serres and Whitehead. In this century, the capacity for knowledge processing in experiments and laboratories has increased, and criticisms have turned towards the method used in the experimenter's positioning and the tools and models used in the observer's experiment.

The scientific practice put forth in the laboratory, according to Bernard Stiegler, deciphers how things work cosmologically while constructing a complex relationship between the experimenter and the material (Stiegler 1998). Although such a intricate process makes the laboratory a controversial place, it allows for a unique practice-space in terms of the density of the relationship between things and humans. The connection between things and humans is unique in terms of the intensity of the relationship. The use of epistemological objects in the social (soft) sciences can be made, and we can speak when we muddy the water, or when we open "semi-objects" such as those mentioned by Barad.

1.5. In terms of experimentality

The definition of experimentality for about 30 years includes incorporating individualized research, i.e., the positioning of the experimenter, into the process of knowledge production. While the experiment itself being a closed process is often criticized, this debate dates back to the relativity experiments in the early 20th century. Today, Latour, Haraway, and Rheinberger argue that every method, every experiment, and every result are as transparent as scientific practice presents to the public. Because such a process of knowledge production is heterogeneous, and only when we muddy the water, or cut "semi-objects" like Barad, social (soft) sciences can look and speak here.

1.6. In terms of producing new agents

Personalized relationships established between matter and the experimenter in natural sciences create some "pioneer objects" that are not real but emerge through new relationships established to realize the idea of research. They perform speculation, create a scenario for the future, and allow the testing of models through the relationships they establish. In the process of scientific observation-experiment, agents who apply the schemas, put them into practice… Following the microscope technology, Gulliver, the variable nature of Maxwell's thermodynamics revealing genie, Schrodinger's cat in relativity, and the mice in the Onco-Mouse project. These are famous characters in experiments. However, in an experiment with an increased knowledge capacity, these agents enable the emergence of epistemological knowledge. And these pioneer objects produce possibilities instead of acting bodies in today's debate. Pioneer objects are forms that allow tracking of repeatable knowledge. These pioneer objects in the process efficiently present a genealogy for practice. Stiegler's "hyper-objects" Schwab's proto-objects, and Rhineberger's epistemic-things are intermediate productions of this experimental process. Experiment and experimentality exist for the interaction of the research object. Each experiment represents representations that create different realities.

Being a "lab" which social (soft) sciences have embraced in contrast to the laboratory, is an effort to critically address scientific practice and is naturally a creative practice. However, the sole reason for the embrace of the "lab fetish" by creative fields is not experimentality, as experimentality is already embedded in the nature of creative practices. Lab, which encompasses multiple individualities for a domain swinging between art and science like architecture, is quite attractive. Research, at this point, highlights the importance of these intermediate products in architectural practice. Instead of providing the same answer under every condition, it reveals a series of possibilities with a laboratory that produces and tests in the same environment. Or it envisions a laboratory that keeps these internal relationships active.

2.0 FROM THE FIELD

2.1. Friedrich Kiesler's 'biotechnology and correlation laboratory'

Kiesler, who poses similar questions in the field of architecture, draws a comparison between chemical molecules and physical atoms, stating that they are creatively the smallest units of the universe with similar production capacities. A significant result emerges from this, where he formulates a research-based practice. He views the

human body as a relatively short-lived, hidden source of architectural potential that shapes matter. Within the framework of biotechnology and correlation, the laboratory seeks to externalize and identify the covert elements that spark human creativity, moving them beyond the confines of the body. Ultimately, the aim is to externalize the processes that unlock architectural creativity.

Kiesler, on the other hand, takes this small part and attempts to construct the larger from molecules, the smallest and common denominator. His research is not selective; on the contrary, he establishes an inclusive and universal language. Similarities in the smallest components of humans, plants, animals, and matter cannot be separated due to the importance of maintaining a balance of various forces. This is because, in the balance of forces, form is said to evolve with evolutionary and environmental factors, and no mortal human can be the sole decisive factor for all powers; the human is an embodied reflection of fragmentary forces. The greatest concern has been to find the heredity of evolutionary knowledge inherited from biology for both the human body and the built environment. As he did in the laboratory environment applications of the scientific disciplines he collaborated with, he first dissects and then recombines humans and (built) environments. Correlation presents realities emerging in various force balances in an evolutionary process by turning into form (Phillips 2015). Looking at Kiesler, it should be noted that his relationships with biology, evolution, and non-human (animal) entities in the Correlation Lab research follow a different orientation than his contemporaries (Phillips 2015). Kiesler never attempts to be the subject that reins in scientific knowledge. Instead of arriving at fundamental beliefs, he designs a discursive space where variables are recorded. In a series of writings in Architectural Record (Kiesler 1937), just before being invited to Columbia University, he describes his expertise in various subjects such as performing arts, archeology, and the living spaces of animals. Kiesler's writings published in Architectural Record are found between pages of building examples and pages of building technology-materials, while in scientific journals, they appear in subheadings or sections used for special issues. Kiesler, by externalizing bodily features, attempts to propose a practice outside the body. The creative agent is a body with relationships and externalized senses. His designs involve the construction of partnerships, not an idealized individual.

CONCLUSION

The evolution of architectural practice—as delineated through emerging critical theories, laboratory methodologies, and a renewed engagement with materiality—demonstrates a transformative shift in the field. This synthesis of theory and practice, from Kiesler's pioneering Biotechnology and Correlation Laboratory to contemporary explorations in post-human and new materialist paradigms, underscores architecture's capacity to interrogate established hierarchies and reconfigure its relationship with both matter and society. By embracing dynamic experimentation and fostering innovative interconnectivity, modern architecture reclaims its role as a mediator between the built environment and the intricate web of natural and cultural forces. Consequently, laboratories have secured their position within the architectural landscape as a direct manifestation of today intellectual and scientific imperatives, serving to forge a design narrative that is unequivocally contemporary.

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Critically Engaging The Past To Build A More Just And Sustainable Future

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ABSTRACT: As the effects of the climate emergency and dwindling planetary resources force a paradigm shift within architecture away from demolition and new construction towards renovation and adaptation of existing sites and buildings, it is becoming clear that both architectural practice and education will have to evolve and adapt to a context in which the vast majority of our built environment already exists. Any approach to designing with the past, however, cannot ignore how buildings embody both material and immaterial heritage as products of the processes of exploitation and extraction that led to the current crises, meaning that our built heritage represents part of both the cause of and solution to the situation in which the practice of architecture, and society in general, now finds itself.

This paper identifies and explores the intersecting challenges faced by contemporary students and practitioners of architecture through the prism of a practice no longer premised on tabula rasa but grounded in adaptation and reuse. In order to bridge the perceived gap between historic preservation and creative adaptation, the paper undertakes a critical analysis and re-evaluation of the concept of heritage. It posits that unlinking heritage from traditional associations with strict conservation can emancipate the architect, allowing an understanding of buildings not as artefacts frozen in time, but living structures that can evolve and adapt to changing needs. By way of illustration, the paper looks to a number of projects by hybrid practitioners currently active across research, education, practice and legislation whose work rethinks what it means to engage with the existing. A critical discussion and comparison of these case studies offers new perspectives on adaptive reuse theories and practices, thereby helping to ensure that current and future practitioners are equipped with the necessary skills and knowledge to work successfully in this changed – and continually changing – reality.

KEYWORDS: Adaptive reuse, heritage, architectural education, architectural practice, climate crisis

INTRODUCTION

This paper was inspired by a convergence of questions and themes that continued to arise during conversations with students, educators and practitioners of architecture on how to deal with the challenges faced by our discipline in the early 21st century. As the effects of the climate emergency and resource crisis continue to unfold around us at an ever-quickening pace, a broad consensus is finally being reached within architectural circles acknowledging that acts of large-scale demolition are no longer justifiable, accompanied by a recognition that instead, existing buildings should be adapted and reused (*Common Ground: Making the Renovation Wave a Cultural Project* 2021). This shift is already palpable in the EU construction industry, where renovation and adaptation currently account for 50% of all activity (The Architects' Council of Europe 2023, 8). Given that up to 95% of existing buildings are expected to still be standing in 2050, it is clear that both architectural practice and education will have to evolve and adapt to a context in which the vast majority of our built environment already exists (*EC Renovation Wave Strategy* 2020).

Designing with the past presents its own set of challenges. While the demise of the default 'blank sheet' approach in architectural education is to be welcomed, students can feel intimidated when asked to intervene in existing buildings or engage with the work of others. The questions this raises with regard to originality and authorship are difficult to navigate, especially for those with little practical experience. Likewise, when heritage is viewed as sacrosanct, creativity can be hampered as students or practitioners question their right or doubt their justification to make changes to protected buildings. On top of this, recent surveys of students, educators and practitioners in architecture and urbanism reveal that many students feel paralysed by the sheer scale of the challenges faced by society, and the burden of responsibility they have inherited (Adapt, Reuse 2024). In order to fully grasp and confront the challenges faced by contemporary practitioners and students of architecture, it is imperative to understand the history, background and causes of these challenges, and the role that architecture and the construction industry has played in creating them.

1.0 A PRECARIOUS PRESENT

1.1. Architecture's material complicity in the planetary emergency

According to UN statistics, the built environment is responsible for 37% of global CO^2 emissions, 10% of which represents embodied carbon (UN Environment Programme 2024). In the European Union, the built environment consumes 50% of all extracted materials, produces 35% of all waste and emits up to 12% of total national greenhouse gas emissions (European Commission 2020). Clearly, the role of architecture and the construction

industry in causing, exacerbating and perpetuating the climate emergency and the depletion of the earth's finite resources is both historical and ongoing.

As architect, scholar and urban designer Charlotte Malterre-Barthes points out, "(e)very element of the built environment is the product of extractive processes":

> Far from being abstract and removed objects, construction commodities are embedded within economic and ideological systems of extracted energy, materials, and labor. At a staggering scale, capital accumulation and the corresponding brutal and exploitative processes at work in the transfer of raw materials to the built environment have long been perceived as detached from the discipline, the education, and the practice of design and architecture. (Malterre-Barthes 2021, 87).

1.2. Architecture's immaterial legacies

In the 2023 Flanders Architecture Institute exhibition *Intersections: Invisible in architecture*, curators Hülya Ertas and Luce Beeckmans similarly highlight the fact that the labour, energy and knowledge of those involved in the production of architecture

> are not equally valorised and the extraction of materials and natural resources often involves obscured processes of exploitation, precarization and marginalization, as well as environmental degradation (Ertas and Beeckmans 2023).

Confronting architecture's material history and legacy must therefore go hand-in-hand with an examination of its immaterial consequences, including its continuing role in perpetuating injustices and inequalities. In *A Manual of Anti-Racist Architecture Education,* Cruz Garcia & Nathalie Frankowski argue that this involves questioning the invisible labour behind architecture, avoiding depoliticised concepts of sustainability, and recognising and centring the social, political as well as historical contexts of architectural movements (Cruz and Frankowski 2023).

1.3. What is our inheritance?

It becomes clear that any approach to designing with the past cannot ignore the fact that buildings, as embodiments of both material and immaterial heritage, also embody the processes of exploitation, extraction and oppression that have led to the current global crises. It is also important to note that the majority of this built inheritance doesn't consist of monuments and listed buildings, but rather a whole host of unspectacular, even mediocre buildings, many of which are undervalued, neglected and vulnerable to dereliction or demolition. At the same time, we have also inherited a planet that is rapidly becoming uninhabitable (Intergovernmental Panel on Climate Change 2023), alongside levels of global inequality that match those seen at the peak of Western imperialism in the early 20th century (Chancel 2022, 12). Taken together this might seem to represent a toxic legacy, but it is one that nevertheless presents an opportunity.

Malterre-Barthes contends that, "a truly sustainable architecture would concern itself instead with the maintenance of what already exists" (Malterre-Barthes 2021, 87). The renovation and adaptive reuse of existing buildings minimises the need to extract new resources, reduces construction waste and can cut embodied carbon by up to 68% compared to demolishing and rebuilding (Foulkes 2023, 9). In this context, our built heritage represents not just the (partial) cause of, but also the solution to the challenging situation that the practice of architecture now finds itself in.

2.0 ENGAGING THE PAST

2.1. Heritage as a discursive practice

Laurajane Smith begins the first chapter of her book *Uses of Heritage* with a surprising statement: "There is, really, no such thing as heritage." Setting out her aim to demonstrate the discursive nature of heritage, she goes on to elucidate that heritage

> is not so much a 'thing' as a set of values and meanings. 'Heritage' is therefore ultimately a cultural practice, involved in the construction and regulation of a range of values and understandings (Smith 2006, 11).

Later in her critique, Smith introduces a concept she terms 'Authorized Heritage Discourse' (AHD), referring to a hegemonic understanding of heritage based on "monumentality and grand scale, innate artefact/site significance tied to time depth, scientific/aesthetic expert judgement, social consensus and nation building" (Smith 2006, 11).

Smith's theories echo those of Stuart Hall, who in *Un-settling 'the heritage', re-imagining the post-natio*n similarly argues that:

> We should think of The Heritage as a discursive practice. It is one of the ways in which the nation slowly constructs for itself a sort of collective social memory (Hall, 1999, 5).

Like Smith, Hall identifies the exclusionary nature of traditionally-accepted and authorised discourses about heritage:

> Like personal memory, social memory is also highly selective, it highlights and foregrounds, imposes beginnings, middles and ends on the random and contingent. Equally, it foreshortens, silences, disavows, forgets and elides many episodes which — from another perspective — could be the start of a different narrative. This process of selective 'canonisation' confers authority and a material and institutional facticity on the selective tradition, making it extremely difficult to shift or revise" (Hall, 1999, 5)

The work of architectural historian Johan Lagae follows Hall and Smith in developing an understanding of heritage as a social construct, one "to which multiple values are ascribed in dynamic processes of (re-)appropriation and negotiation" (Lagae 2008, 15).

2.2. Heritage as a cultural process

Architectural and urban historian and theorist Françoise Choay describes how over the last hundred years, heritage has come to encompass not just historic monuments but also vernacular and industrial architecture (Choay 2001), further illustrating how definitions of heritage are continuously evolving and expanding. Karina Van Herck, a

specialist in built heritage, insists that heritage and architecture should not be thought of as being in opposition, but rather represent a dialogue, since conservation practices and new interventions need not be mutually exclusive (Van Herck, in debate during the As Found colloquium on Adaptive Reuse, Hasselt University, September 2023). Both Choay and Van Herck seek to expose and dismantle a commonly-held misconception that Hall had previously drawn attention to, namely:

> the emphasis given to preservation and conservation: to keeping what already exists — as opposed to the production and circulations of new work […] which takes a very definite second place.

Rather than viewing heritage primarily in relation to the past, Hall advocates instead for understanding it as:

> the active production of culture and the arts as a living activity, alongside the conservation of the past" (Hall, 1999, 3-4).

3.0 MATERIAL AND IMMATERIAL HERITAGE

3.1. Historic preservation versus creative adaptation – coexistence or conflict?

While architectural practices that engage with existing buildings through adaptation as opposed to mere preservation fully embrace more open understandings of heritage as a dynamic cultural process, those responsible for safeguarding built heritage are not always quite so enthusiastic. One example is the case of *Open for Maintenance*, the project for the German Pavilion at the 2023 Venice Biennale of Architecture. Here, the team of Büro Juliane Greb, ARCH+ and Summacumfemmer chose to work with the existing material, social and urban conditions, retaining the space "as found" as much as possible. This included keeping the existing installation created by Maria Eichhorn for the 2022 Biennale of Art, entitled *Relocating a Structure*. Eichhorn had revealed how the current pavilion actually consists of two structures, the Bavarian Pavilion built in 1909, and a radical reconstruction and extension undertaken by the Nazis in 1938 (Declercq 2022). She excavated foundations and removed layers of plaster to expose the outline of the original pavilion, contrasting its more human scale with the intimidating, monumental character of the present structure. Using only materials salvaged from the previous year's art biennale, the *Open for Maintenance* team saw an opportunity to subtly subvert this architectural ideology of domination and exclusion, "in a political and cultural sense, but in a physical one as well" (Femmer et al 2023, 3). One key intervention was to add a wide curving ramp to the massive columned entrance portico which had previously been separated from the Giardini by five steps, thereby

> facilitating access not only to visitors with reduced mobility, but also to cleaning personnel, guards, and technicians with heavy equipment (Femmer et al 2023, 3).

Although the German ministry of culture was open to making the ramp permanent, the Italian heritage authorities responsible for the site would not allow it, despite the fact that the building had already undergone various changes throughout its history. As a result, the ramp was removed and the pavilion returned to its Nazi-era state, representing a wasted opportunity to correct a historic wrong. As Hélène Frichot reminds us, sometimes by preserving such infrastructures, we maintain the status quo (Frichot 2023, 27), which in this case meant perpetuating the marginalisation of "groups and bodies disadvantaged by ableism" (Femmer et al 2023, 3).

3.2. Existing qualities, existing elements: Théâtre des Variétés, Brussels

Taking a different approach, architects Flores & Prats write that

> The idea of heritage has nothing to do with what is valuable or monumental, but arises from time and experience [...] this condition is present in ordinary architecture, accumulated in an infinite number of layers, latent in every detail, ready to reawaken in our memory (Flores & Prats 2023).

They refer to their project to transform the former Théâtre des Variétés in the centre of Brussels into a cultural centre and creative laboratory, undertaken in collaboration with Belgian practice Ouest architecture. This building, which first opened in 1937 but has lain derelict for almost four decades,

> was deeply rooted in the memory of the city's inhabitants: it had formed part of the cultural life of Brussels throughout the whole 20th Century. It had gone through several different usages and occupations, some of them quite aggressive, such as the squatters who partially burnt it down in the late 1980s. But we still came across some lingering 'ghosts' of the former theatre (Flores & Prats 2023, 48).

The proposal by Flores & Prats and Ouest aims to create two new concert halls, a café bar, a foyer and a new public street inside the existing volume. Because the theatre had originally been designed by renowned Belgian architect Victor Bourgeois in collaboration with Maurice Gridaine, the heritage administration had classified the existing façade, roof and stage. However, after a preliminary feasibility study was commissioned by the new owner, it became clear that due to contemporary acoustic regulations, it would be impossible to reuse the stage and concert hall in their current form. The existing metal roof likewise represents a safety hazard according to contemporary fire prevention regulations.

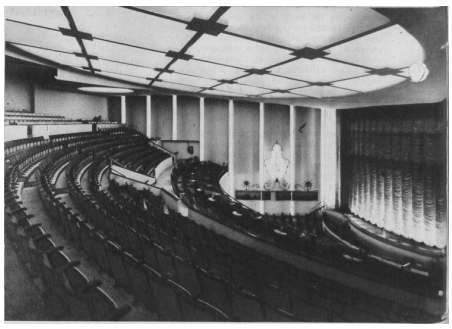


Figure 1: Magazine article photograph showing the original chequerboard rooflight. Source: (BATIR 61, December 1937)

This roof originally incorporated a huge, retractable glass and metal skylight in the shape of a circular chequerboard, which could be opened to bring daylight into the space below, or lit artificially with integrated neon lights when closed (Figure 1). Unfortunately it was plagued with problems from the beginning – the opening mechanism kept getting stuck, and water started to infiltrate almost immediately. The retractable rooflight effectively stopped operating only one year after the theatre opened, and was eventually covered over with roofing felt.

In this particular case, the architects benefitted from a constructive relationship with the heritage authorities, who were very enthusiastic about the prospect of a project that would return the building to a use and state very close to what was originally intended. The Royal Commission for Monuments and Sites (CRMS), an advisory body that advises the Government of the Brussels-Capital Region on matters of protection and conservation of built heritage, noted that since the roof and the stage area no longer met contemporary requirements for acoustics or fire safety, they would be open to the architects finding a way to preserve the existing *qualities* of these elements, rather than insisting that they preserve the original material *elements* themselves. For this reason, they recommended delisting the roof and stage, meaning only the façade remains classified (CRMS 2016, 5-6).



Figure 2: Visualization of the proposed new rooflight above the stage. Source: (Flores & Prats / Ouest Architecture 2023)

This decision permitted the team to set about answering the question of how to work with the existing *quality* of bringing daylight in through the roof, despite the fact that the original *element* designed to achieve this quality never quite worked. Since in the new proposal an additional concert hall is being inserted above the existing roof (which needs to be removed for the aforementioned safety reasons), it is no longer possible to install a rooflight over the audience seating as per the original 1930s design. By way of solution, the architects have looked to the existing fly tower over the stage. While this will be retained, its roof structure is not compliant with contemporary fire regulations and needs to be upgraded. Ouest and Flores & Prats propose to use this opportunity to install a glazed rooflight that will once again bring daylight into the centre of the main space (Figure 2).

During a conversation with project collaborator and lead architect at Ouest Stéphane Damsin, he describes how placing more emphasis on immaterial heritage qualities as opposed to material elements shows an understanding on the part of the heritage authorities

> that classifying too much would be against the reuse and rebirth of the building. To me, that demonstrates a progressive attitude (Stéphane Damsin in conversation with the author, Brussels, July 2023).

3.3. A gradient from protection to safeguarding: Royale Belge, Brussels

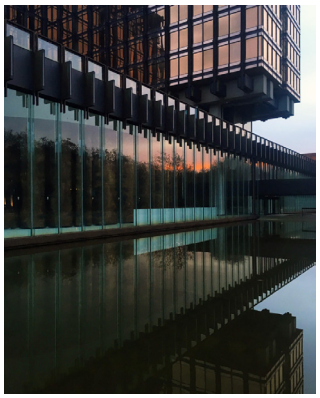


Figure 3: The original façade of the Royale Belge building. Source: (Author 2017)

The evolving relationship between preservation and adaptation similarly proved to be a deciding factor in the fate of the Royale Belge, a former office building on the outskirts of Brussels that in 2023 was renovated and adapted by Caruso St John Architects and Bovenbow Architectuur to become a hotel, food hall and leisure centre. Originally designed by architects René Stapels and Pierre Dufau, it was inaugurated in 1970 as the headquarters of the insurance company La Royale Belge. The most distinctive feature of this building is its external bearing CorTen

steel façade, resting on exposed concrete elements and supporting a glazing system of golden-orange tinted glass, which can seem either transparent or reflective depending on the light and the angle of view (Figure 3).

In 2017, the building was threatened with demolition when the government of the United States agreed to purchase it, intending to tear it down and build their new embassy on the site. These plans were thwarted when, at the request of the local municipality, the Brussels regional government intervened. The US had presented demolition and reconstruction as the only viable future for the site, arguing that if the region listed the building (as they were considering to), it would prove impossible to reuse because the necessary modifications would never be accepted in a protected building (RTL Info 2017). However, this reasoning failed to take into account the gradient of approaches that urban.brussels, the government agency responsible for regional policies related to urban planning and cultural heritage throughout the Brussels Capital Region, has developed with regard to the recognition and safeguarding of heritage. Harry Lelièvre from urban.brussels outlines the two main instruments involved:

> The Inventory (of Immovable Heritage) involves cataloguing significant heritage objects and sites, while the Register (of Safeguarded Heritage) serves as a record of safeguarded and protected heritage objects and sites (Lelièvre 2024, 53).

He goes on to explain that

> While both are legally binding, an important distinction exists between safeguarding and protecting. This distinction does not hinge on the intrinsic value of the heritage, but rather on their approach: protection seeks the strict preservation of heritage, whereas the status of safeguarded heritage allows for more flexibility (Lelièvre 2024, 57).

The US eventually abandoned their embassy plans – and the site – when the Royale Belge was added to the Register of Safeguarded Heritage. This meant that while the building could not be demolished, a range of interventions proposed by the team of Caruso St John and Bovenbouw that normally wouldn't have been possible in a protected building were in this case permitted, including the insertion of new vertical circulation that necessitated the partial demolition of the interior. Similarly, while the steel façade was retained, the glazed exterior skin was completely replaced with visually similar glass, the original being unable to meet contemporary energy and thermal performance requirements. Lelièvre see this as a reflection of

> evolving preservation practices: the preservation efforts aimed at maintaining the aesthetics of the appearance rather than the historical integrity of the materials (Lelièvre 2024, 57).

4.0 FROM DUALITY TO DIALOGUE

4.1. Hybridity and adaptive reuse

The examples of Variétés and Royale Belge bear out Katrina Van Herck's assertion that the relationship between architects and heritage authorities – in Belgium at least – appears to be changing. They prove that historic preservation and creative adaptation can coexist, and even complement one another, when both are approached holistically in a pragmatic manner that balances heritage considerations with the practicalities of continued use. "It's not a duality," remarks Stéphane Damsin of Ouest, "It's more of a dialogue". Such refusals to recognise or accept a strictly dichotomous or binary relationship between existing heritage and proposed interventions substantiate the theories of Stuart Hall, who maintains that across generations, traditions can coexist with

> …the emergence of new, hybrid and crossover cultural forms of tremendous vitality and innovation […] This is a new kind of difference — the difference which is not binary (either-or) but whose 'différances' (as Jacques Derrida has put it) will not be erased, or traded (Hall, 1999, 9).

Hybridity is a common feature found not only across adaptive reuse projects and practices, but also in the practitioners themselves. In the case of projects, it reflects how the new use of the building is grafted onto its previous lives without the need to erase or prioritise a given era over another, reminding us again that architecture, much like heritage, does not remain static but represents a process of continuous evolution. With regard to hybrid practitioners, it refers to those whose work spans practice, education and theory, as well as individuals and organisations active across research, design and construction.

4.2. Architecture as an ongoing process: Charleston in Lewes, UK



Figure 4: Stripped back interior with exposed brickwork, Charleston in Lewes. Source: (Material Cultures / Henry Woide 2023)

A case in point is Material Cultures, a UK-based multidisciplinary, not-for-profit design and research organisation set up in 2019. Their recent project for the Charleston Trust in Lewes, UK, demonstrates how the concept of an architecture that is still in process was central not only to gaining the trust of the client, but also to completing the project on an impossibly tight schedule and budget. Tasked with turning former council offices into a gallery and cultural space for an arts and culture charity with limited funding, the architects and client together took a pragmatic decision not to try to achieve all of the works initially envisioned. Instead, they agreed on a strategy of minimal intervention and material economy that would reveal the potential of the building with a view to possibly carrying out a more comprehensive renovation at some point in the future, should funds become available. This permitted

quick decisions and compromises to be made, allowing some features to be kept that ordinarily might not have been, such as the irregular brick finishes (Figure 4).

Stripping back not only revealed the original structure of the building, it also exposed the various ad hoc interventions that had been made during the building's lifetime by various inhabitants. Rather than try to restore the building to some imagined ideal state or cover up these often messy interim solutions, the architects left visible the traces of each phase of the building's history. The client was able to accept this raw aesthetic, partly because they knew it would not necessarily always remain like that. This quality of unfinishedness was even leveraged as a strategy to raise funds and support for a possible next phase, by revealing the potential of the building while simultaneously highlighting that it is very much still a work in progress.

4.3. Establishing architectural quality through adaptive reuse: Karreveld, Brussels

The project for Charleston in Lewes differs from those for Variétés and Royale Belge in that the building was not listed, meaning the architects faced fewer restrictions with regard to how it could be adapted and reused. However, by the same token it represents an example of how acts of transformation can produce architectural and cultural value, even when the building in which they intervene is not viewed as having any established heritage value. Such cases strengthen the argument that heritage need not be restricted to listed buildings (such as those aligning with Smith's 'Authorized Heritage Discourse') by proving that the quality of an architectural intervention of reuse is not dependent on whether or not the existing building is perceived to possess any architectural merit.



Figure 5: Interior of Karreveld school. Source: (AgwA / Séverin Malaud 2021)

The Karreveld project by AgwA in Brussels likewise shows how interventions of adaptive reuse can transform even somewhat mediocre buildings with no discernible heritage value into interesting and purposeful architecture. Involving the transformation of a former factory into a school, this project was intended as a temporary first phase in a longer term evolution, as was the case at Charleston. Here again, the project featured a very short timeframe and an almost non-existent budget, which forced the architects to work with the existing elements that were already on the site, dismantling very standard, run-of-the-mill modular interior systems and reinterpreting them, adding new elements where necessary (Figure 5). The result demonstrates that just as heritage is created through a continual process, architectural quality – and along with it, cultural and social value – can be created through the various interventions that occur during the ongoing life of a building.

5.0 LESSONS FOR CURRENT AND FUTURE EDUCATION AND PRACTICE

5.1. Challenges in architectural education

A recent survey conducted by research and knowledge-sharing platform Adapt, Reuse set out to investigate the challenges faced by both students and educators in contemporary architectural education (Adapt, Reuse 2024). While it is encouraging to see that when asked about their design studio projects, a majority of respondents (84.2%) claimed to have worked to some extent on the adaptive reuse of existing buildings, with only 15.8% designing new buildings on a cleared site, many students also indicated that in projects of adaptive reuse they find themselves posing questions such as 'How far can I intervene in an existing building?' (89.5%), 'What changes to the building am I allowed to make?' (68.4%), and 'How can I justify my proposed interventions?' (63.2%). Interestingly, when asked what they thought represented the main challenges currently faced, the joint top responses (at 68.4%) from the students surveyed were the climate emergency and the loss of skills and knowledge. Asked to elaborate, most students claimed that they didn't feel equipped with the necessary design tools or skills to solve the real life problems they would face in their professional working life. Many complained of insufficient focus on future-proof materials and sustainable construction methods, others pointed to a lack of practical knowledge, while still others called for more engagement with and exposure to the world outside the studio environment (Adapt, Reuse 2024).

5.2. Adapting to reuse: addressing the skills gap required for a post-carbon built environment

These are precisely the types of issues that Material Cultures, mentioned earlier, set out to address. Alongside a focus on hands-on approaches and bio-based, locally-sourced materials, one of their central missions is to address the significant skills gap in our current architecture and construction industry as a way to counteract the lack of technical knowledge and skills required for a low carbon transition. As well as undertaking architectural design work as a way to apply the principles and knowledge developed in their research, Material Cultures are also active in the educational sphere, teaching design studios at different academic institutions where the emphasis is on learning through making. They have also set up a learning platform, MAKE, that foregrounds practical and accessible construction skills. In collaboration with a range of partners, MAKE organises practical, hands-on workshops that

give students the opportunity to co-construct buildings through on-site experimentation with timber frame construction, insulation, cladding, plastering and other techniques (Material Cultures 2024).

5.3. From linearity to circularity: reuse and regenerative building materials

De Pastorie, an ongoing live project by the students of the postgraduate course Building Beyond Borders at the Faculty of Architecture and Arts in Hasselt University follows a similar pedagogical approach. Undertaken in collaboration with Living Lab Leemsteen, BC materials, and local actors from the non-profit community association de Pastorie, it involves the restoration and reuse of a former rectory in Helchteren, Limburg, which had lain abandoned for many years. Unable to find a buyer for the building, the local municipality decided to give it a public function by turning it into a hub and resource centre for the local community. According to Hanne Kellens, councillor for youth, culture and heritage, while the project respects the “authentic historical appearance of the building”, the aim is not to deliver a “classic” renovation but rather a “practical” one that will ensure de Pastorie can adapt to multiple arrangements and layouts (Nelis 2024). This further corroborates a pattern already discussed, whereby local authorities increasingly demonstrate a more progressive attitude towards heritage that seeks to balance preservation with pragmatism by taking into consideration the ecological, social and cultural dimensions.



Figure 6: Students working on site at De Pastorie. Source: (Building Beyond Borders / Nijs de Vries 2024)

The students from Building Beyond Borders have recently completed the first phase of this participatory, self-designed, self-build project, using only hyperlocal, sustainable building materials to construct a garden pavilion and outdoor oven (Figure 6). Resolving not to purchase any new materials, the students set up a workshop on site which allowed them to hand produce unfired earth bricks and wooden roof shingles sourced from a local forest. They also engaged in urban mining to salvage and reuse materials such as tiles, bricks, sand and gravel from houses in the vicinity that were being demolished to make way for a new infrastructure project.

The hands-on approach of live projects like these helps students overcome their paralysis by encouraging them to think through doing. This teaches students invaluable practical skills, which in turn gives them confidence to become capable designers who understand the materials and processes of building. As the projects presented here illustrate, such approaches dovetail neatly with practices of adaptive reuse. They take existing sites, resources and know-how as starting points from which to explore the possibilities offered by craftsmanship to develop inventive solutions using regenerative materials, with a shared goal of fostering a more sustainable and inclusive society.

CONCLUSION - INHERITING THE FUTURE

The theories, practices and projects explored in this paper all seek in their own way to untangle the seeming dichotomies of then and now, past and present, tradition and innovation, thinking and doing. As actors who combine pedagogy with practice and design research with construction, all of the practitioners examined actively strive to break down knowledge silos, transgressing disciplines to enable ways of working with both the existing built environment and the work of others. Unafraid to engage with recent buildings, no matter how banal or ordinary they might be, their work helps broaden the scope of what can be considered heritage, thereby freeing it from restrictive definitions that perpetuate artificially-constructed divisions between conservation and intervention. They share an understanding that, at its core, adaptive reuse is not just about preserving the past, but rather engaging it with a critical eye. This point is crucial: if we are to avoid repeating the same processes that brought us to the current emergency of the Anthropocene, we must change the way we build. Transforming buildings therefore needs to go hand-in-hand with transforming the practice and education of architecture, and society in general.

While the theme of this conference is ‘Architecture into the Unknown’, we have lately moved much more quickly into uncharted territories than we ever could have imagined only a year ago. In her opening address which reflected on architectural education as an agent of change, Dr. Oya Atalay Franck stated that being an agent of change means not only caring, “it also means taking action” (Atalay Franck 2024). Over the past few months, we have witnessed students across the world step up and take action to kick-start the most widespread, co-ordinated protest movement of the 21st century. These actions have been precipitated by a sense of extreme urgency: the same lack of will that has seen politicians and governments fail to adhere to either the Paris Agreement or the recommendations of consecutive IPCC reports is mirrored in the apathy and political inaction they continue to show in the face of ongoing ecocide, urbicide, educide, ethnic cleansing, and genocide around the world (Peters 2024), in Palestine, Congo, Sudan, Ukraine, the Amazon… the list goes on. Not only are we facing climate and biodiversity breakdown, spiralling inequality, and unprecedented population displacement, we are also witnessing the breakdown of international law and the rules based order (Callamard 2024). But just as live projects encourage

students to take what they've learned and apply it to the real world, these intersectional protest movements represent a similar transdisciplinary approach to the problems at hand. As Ertas and Beeckmans state,

> Architectural production does not happen in a void but is shaped by the social, cultural, economic and political structures of power that define our society (Ertas and Beeckmans 2023).

If we are to have a future to inherit, it is essential to have an understanding of the context in which architecture is produced, including how it has the potential to contribute to the climate crisis, growing inequality, and the many other issues and injustices facing our societies today. Acknowledging this will empower students and all current and future practitioners of architecture to tackle the many and crosscutting challenges that lie ahead.

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School Architecture – Between Ideas of Space and Lived Space

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ABSTRACT: This article sheds a critical light on the making of Danish school architecture year 2015-2020. It points to barriers in architects' practices and a discrepancy between the ideas of future school architecture and the conditions of teaching and studying in the school spaces. Philosopher and sociologist Henri Lefebvres' theory and concepts of space are used to investigate this discrepancy with the perspective of how school architecture is produced socially. Lefebvre's social ontological stand and anthropological approach to space provide a framework to an analysis that spans from the ideas of future schools and their materialisation to the teaching practices and the lived life in the schools. This article refers to my PhD dissertation, *Øjeblikkets skolearkitektur. En analyse af de rumlige momenters praksis med fokus på inklusion* that provide a more nuanced analysis of the school political and societal drivers, cultural terms, and bodily perceptions of school architecture. In the following text I address the research question: *How does school architecture emerge between ideas of space and lived space in school?* My answer to this question draws on the analysis of pedagogical and architectural school briefs and architects' drawings of schools, as well as field observations in three of the schools, and interviews with consultants, architects, teachers and students. Also, a qualitative survey among all teachers in the schools has been caried out. The research points to that ideology of the future school suppresses the voices of teachers. The findings show that some tenders with an architectural competition prevent architects from communicating with the teachers at the most critical part of the design process. Post-occupancy studies in the built schools briefed 2015-2020 reveal that teachers find difficulties to teach inclusively due to the architecture. It appears that students seem challenged by the teaching practices which contrasts sharply with the visions embedded in the pedagogical and architectural school briefs 2015-2020. A further discussion is suggested on how social practices in the design of future welfare architecture can enhance and ensure social sustainability by promoting care, community, and belonging with the architecture.

KEYWORDS: School Architecture, Henri Lefebvre, Representations of Space, Inclusion, Social Sustainability

INTRODUCTION

The motivation for my research occurred at a newly built school, Frederiksbjerg Skole, in Aarhus 2016. I was conducting field observations of the school's hallway with a staircase combined with a characteristic climbing wall when a teacher of children with special needs approached me. After noticing that I was an architect the teacher said:

> *I've had a lot more on my plate since we moved into this new school building, and I'm sure it's because of the school's architecture.* (Teacher of Special Education, Frederiksbjerg Skole 2017)

The number of students referred to the department of children with special needs had increased in the new school building. I found that devastating because it's been a political goal since the Salamanca Declaration to create a more inclusive public school in Denmark (Undervisnings- og forskningsministeriet, 1997). Also a School Inclusion Act was passed year 2012 to reduce the percentage of challenged students segregated from mainstream education from 5.5% to 4% (Weirsøe, 2021). In 2014, as well, a school reform was implemented to encourage movement in the Danish public schools, primarily for the sake of active boys who have difficulties sitting still (Réol, 2016). The stairway of Frederiksbjerg Skole was designed as part of an inner atrium that contains 20 physical activity stations. The school had won several architectural awards since opening and architects were visiting to study a future-oriented innovative school that is able to promote new teaching practices with more movement. In recent decades, school architecture, in general, has been used as a tool to radical change teaching practices to what is considered to be more student-centred and inclusive (Benade, 2019; Bertelsen & Rasmussen, 2018; Daniels, 2018; Imms & Mahat, 2020; OECD, 2015, 2017). I therefor found that the discrepancy between the ideas of an innovative school and the teachers experience highlighted a need to investigate the ideas for future school architecture in Denmark the transformation into briefs and school design, and the teaching practices taking shape in the school buildings. I therefor ask:
How does school architecture emerge between ideas of space and lived space in school?

1.0 METHODOLOGY AND THEORY

The historical period of the research is defined by nine pedagogical and architectural briefs for public schools from year 2015-2020 which form the basis of analysing the ideas of future schools. Interviews with three authors of the briefs and six architects of the winning school projects provide further insight into how the visions have been transformed into a school design. To learn about the dialectics between the school architecture and pedagogical practices within, post-occupancy studies has been carried out of teachers' didactical practices in grades 4 to 6 in

three of the schools briefed 2015-2020. The post-occupancy studies include observations, photographing and filming teachers' and students' movement patterns, gestures and social interactions during the teaching. For ethical reasons, the illustrations from the architectural competitions are pseudonymized. This ensures that critical analysis of the work remains focused on position and possibilities within the social practices rather than on identifying specific architectural offices or schools. The methods are carried out with a sensory ethnographic approach to engage both physically and mentally with space and social life when observing (Pink, 2015). In this approach, I draw on my dual educational background as both former architect and teacher in the Danish ground school. The interviews conducted with school leaders and teachers from middle-level in the schools are compared to answers from a qualitative survey sent to all teachers in the three schools. Films, photographs, observations and insights from the interviews have finally been used to unfold vignettes of challenged students' moments with the school architecture (Bloom-Christen & Grunow, 2022) which can be found in my PhD dissertation (Gjessing 2025).

The empirical material enables an analysis through Lefebvre's' three concepts of spatial moments, introduced in the book *The Production of Space* (Lefebvre, 2016). Lefebvre presents three spatial moments that can be understood as different dimensions of architecture. The three moments are gateways to reveal an ongoing spatial triad through which architecture can be analysed. The moments are conceptualised: *The Representations of Space*, *Spatial Practice* and *The* (*Representational*) *Lived Space* (Simonsen, 2010). The model below illustrates the empirical material of the analysis through Lefebvre's three moments: the mental and visual conception of space, the daily practice with the architecture, and the individually sensed and experienced space. In the analysis Lefebvre's' theory is combined with further theory that deepen the understanding of the spatial moments. Analysing The Representations of Space, critical discourse theory of Norman Fairclough is applied to share light on the discursive and social practices between decision-makers, consultants and architects in the briefing and design of a school buildings (Fairclough, 2010). Practice based theory of inclusion in school by Lotte Hedegaard-Sorensen supplements the analysis of *Spatial Practice* and *The Lived* Space (Hedegaard-Sørensen, 2021; Hedegaard-Sørensen & Grumløse, 2016). Hedegaard-Sorensen's theory supports understanding the didactical possibilities of inclusive teaching with the spaces.

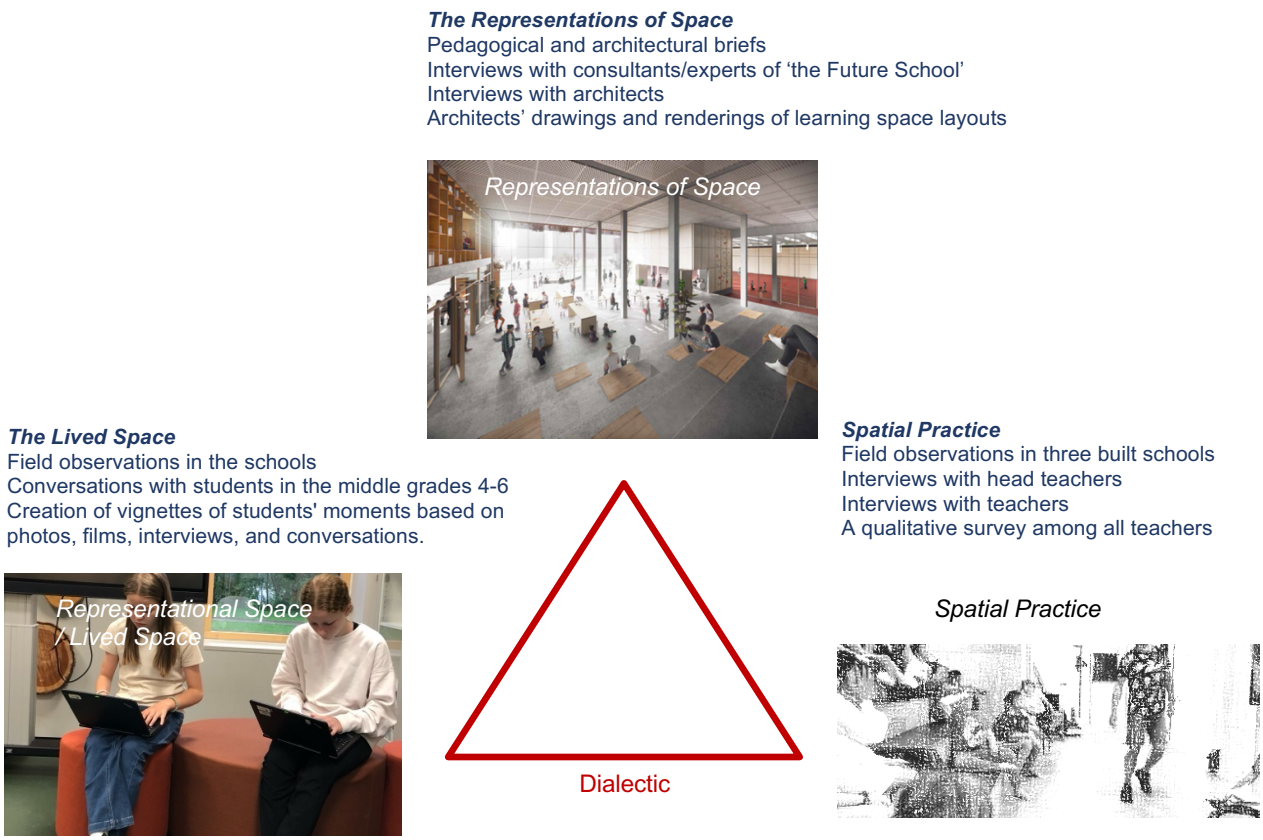


Figure 1: The model illustrates the strategy of how the school architecture has been analysed. The analysis builds on Henri Lefebvres' work *The Production of Space*. (Lefebvre 2016). Source: (Eva Gjessing 2025).

2.0 THE BRIEFS

The analysis of the texts from briefs 2015-2020 reveals a hegemonic discourse with the common perspective that a radical change in the layout of school space is needed. This I find calls for further investigation into international influence and drivers behind the strategy of future schools in Denmark. However, within the limits of this research, I rely on the words of the architects and Danish consultants interviewed. The consultants present themselves as experts in future schools and 'Bridge Builders' between pedagogy and space. The group of Danish pedagogical consultants in school architecture is a small group counting especially three strong voices that repeat across the

pedagogical and architectural briefs investigated. Sometimes two consultants are engaged in the same project as one consultant facilitate user involvement and stakeholder inputs transferred to information to another consultant who writes the pedagogical and architectural brief. Despite the money and time invested, the strategy of the school architecture appears to be somewhat fixed and defined beforehand the user involvement. A consultant describes:

> *Some decision-makers need to be led by the hand, and some want a lever into the new. I can see decision-makers who have a vision but can't push it through when facing the users and employees, who therefore need an intermediary, who speaks from the outside and qualifies the strategy of the future school….* (Pedagogical consultant 2023).

The authoring of the brief tends to be less restricted the smaller the municipality is. The largest councils have a department with architects to ensure the planning and economy of new schools. This is not the case in the smallest municipalities of Denmark, where consultants are hired project-wise. In those cases, the consultant mostly has huge freedom in writing the brief of what is called a new kind of school architecture with new teaching practices adapted to new learning technologies and an information-driven future. Spatial diagrams in these briefs suggest a revolution of the traditional school architecture structured with classrooms. Instead, these briefs promote 'learning landscapes' with open, varied, and flexible learning spaces that is said can accommodate well the variety of different types of students. The vision is to change school architecture from framing a teacher-centred school to a student-centred one that is inclusive due to new kinds of didactical practices and new ways of organising teachers and students.

2.1 The double illusion

The desire to dismantle the teacher-centred school is part of a discourse exemplified by the global strategy for future schools in OECD reports (OECD, 2015, 2017). OECD promotes a necessary 'de-schooling' of the existing school system to create a more cost-effective one better able adapting to ongoing technological developments and quickly changing economic demands (OECD, 2013). The potential to create a more cost-effective school system is attractive to the Danish municipal decision-makers who close small, outdated schools in exchange for mega schools hoping for a more efficient use of the square metres. An architect explains that economic efficiency in the design and future operation of the school is an important design parameter, along with the creation of a more inclusive school:

> *But you know, I find that the economy and the austerity measures of the municipalities end up leading the way... because they don't have the budget, and then one must start to be creative ... because there's a certain number of students, then you must gather the spaces and make them flexible. I'm sure we've spared a lot of square metres by planning it all together in a huge workshop-like environment offering a multi-flexible solution.* (Project architect with 15 years' experience in school design 2021).

The analysis of the spatial moment The Representation of Space points to that inclusivity and economic efficiency are twin objectives that go hand in hand in the design of Danish future schools. The first objective, inclusivity, seems to be dressed in the ideology of liberating the school child. It is proclaimed in the briefs and to the users that students are better included when freed from a constricting classroom that is controlled by the teacher. The second, cost-effectiveness, is quietly hidden from the users but emerges in the architectural competition process. Lefebvre find that this kind of capitalist production of space operates as a *Double Illusion* with two sides which ' - *refers back to the other, reinforces the other, and hides behind the other.'* (Lefebvre, 2016, p. 27). One side represents the logic of calculation the other a sensual fascination of the deliberated body of the school child. Lefebvre's concept, I find, points to the illusionary gain of reassigning children with special needs to mainstream education while at the same time cutting down the budget of new square metres of the mainstream educations school architecture. However, it seems that is what many decision-makers are misguided to believe when consulting some of the Pedagogical Experts in future school.

2.2 Discursive- and social practices within a school competition

When participating in an architectural competition architects meet barriers. These barriers can be revealed with theoretical concepts Discursive Practice and Social Practice of Norman Fairclough, concerning the discursive making and distribution of the briefs and concerning the cooperation, positions and procedures of a tender that contains an architectural competition (Fairclough, 2010, 2015). Architects complain that designing a school require more knowledge than what can be read from a piece of A4 paper in a brief. However, this is precisely what the architects find themselves left with, during the critical part of the design process when they participate in an architectural competition. In the design process, architects are restricted from contacting the users, a restriction that is maintained from prequalification to the nomination of a winning school project. An architect regrets that they can't even write a mail to the users of the school when designing the layout of the building:

> *The rules of the architectural competition ensure that those drawing the schools are disqualified if they make any contact with the users during the design process. They thus construct an iron fence between those designing and the users of the design, and this iron fence is maintained… through the project development until a winner is nominated, and when this happens the critical parts of the school building are fixed'* (School project architect 2021).

More architects are frustrated by the experience of encountering disillusionment and criticism from teachers when presenting the renderings and floor plans of the winning school project to the future users after the nomination. Fairclough's theory shows that the brief's discourse is dialectically related to the discursive practices of the architectural competition based on a brief, which is dialectically related to and embedded in the social practices of how new ideas of future schools are promoted (Fairclough, 2010). How the ideas take shape constitutes how the architectural competition proceeds and how the consultant creates the text of the brief. In this sense, the consultant's work can be understood as representing the municipal decision-maker's expectations. The iron fence between the users and the architects can be seen to support that the strategy in the text of the briefs to stay strong and is carried out without critical questions from either architects or users.

3.0 FROM BRIEF TO ARCHITECT'S DRAWINGS

The architects' position in these Discursive - and Social - Practices leaves the one and only option to design the school according to the text and strategy of the brief. Following this, I find, that the architects' work can be seen as an additional representation of the idea in drawings and renderings. This transformation from one representation in text to another, more convincing and sensuous representation in joyful drawing is according to Lefebvre's theory a *Mediation*.

> 'The design serves as a mediator – itself of great fidelity – between mental activity (invention) and social activity (realisation)' (Lefebvre, 2016, p. 27).

In this light the architects work can be seen as creating symbols of future school architecture rather than showing real-life space. Symbols, that Lefebvre calls *Material Signifiers* (Lefebvre, 2016), which tend to be adopted and copied from one architect's office to another when designing school building when designing imagined representations of space instead of bodily sensed and experienced lived spaces

The winning architect's office will be the one that best expresses the visions of the brief. However, it is the architect's responsibility to combine the brief with a building budget that the author of the brief has not been obliged to consider. To win the competition, I therefor conclude, that the architect necessarily must visualise convincingly that the dream of an emancipated child is possible within the cost-effective construction budget submitted to the architect together with the brief. The budget obliges the architect to carefully count the choice of materials, construction and, later, the interior of the building but this rarely affects the atmosphere and glamour of the renderings in a school competition project. Lefebvre found images more likely to promote fallacy and illusion than to demonstrate the reality:

> Where there is error or illusion, the image is more likely to secrete it and reinforce it than to reveal it. No matter how beautiful they may be, such images belong to an incriminated 'medium' (Lefebvre, 2016, p. 96).



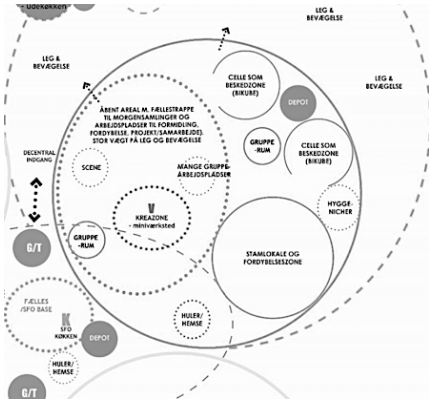
Figure 2: A typical rendering from a pseudonymized school project in 2021. Source: (Anonymous 2021)

The analysis shows that the position and work of the architect in a school competition supports ideas of school that are far from practice and the daily lives of students and teachers. It reveals that the practice of architects in an architectural school competition aims to convince the municipal decision-makers of the reliability of the consultant's vision of the future school. Hereby the architects can be seen as mediators of the text in the briefs when they draw compelling images of an inclusive and more cost-effective school, decorated with material signifiers that symbolise the fulfilment of a double-sided illusion of what the student-centred school will be like.

3.1 Diagrams for learning spaces

The texts in the pedagogical and architectural briefs refer to the need of creating more and larger common spaces. Therefore, corridors and stairwells are transformed into wide and open learning spaces and amphitheatre-like staircases where a huge number of students can gather for a common introduction to a new learning content. Classrooms are transformed into flexible learning spaces and made smaller to leave more square metres for common area. The flexibility required of the enclosed learning spaces allows freedom in the schematic organisation of lessons and learning spaces ensuring that the square metres are used effectively leaving no space empty. Instead of having ownership to a classroom, groups of students shift between learning spaces that are assigned a certain subject or specific learning activity. In addition to the text of the briefs, diagrams illustrate how the learning spaces should be laid out to support new teacher practices and new ways of organising teachers and students.

A.



B.

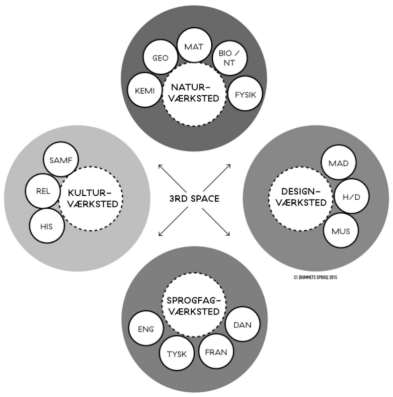
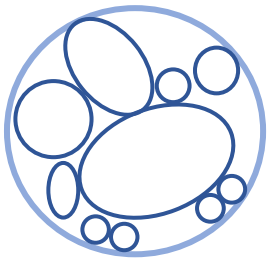


Figure 3A and 3B: Diagrams of the layout of learning space for students grades 4-6. **Figure 3A** (left) exemplifies the layout of an open-plan 'learning-scape'. Pseudonymized school brief: (Pseudonymous 2017) **Figure 3B** (right): exemplifies subject-related learning spaces clustered around a Third Space. Pseudonymized school brief: (Pseudonymous 2015).

3.2 From diagram to floorplan

By interviewing the architects and comparing the floor plans of winning school projects commissioned in 2015-2020, I have found two typical floor plan models emerged from the requirements of the briefs. One model, that I call 'The Capsule', is a larger open 'learning-scape' containing different learning zones, enclosed spaces that differ in size, seating arrangements for groups of 1-8 students and a large learning staircase for gatherings of all students. The Capsule contains all students in a year or, in smaller schools the whole mid-level students' department. The other model, 'The Flower', has a layout of more equal-sized enclosed learning spaces grouped around a shared central space. The shared common space is called *Third Space* by consultants and architects and takes when multi-storeyed the form of a two or three storey high atrium. The Third Space is designed to provide an additional learning space to the enclosed learning spaces that when multi-storeyed often provides a stair to gather more classes of students.



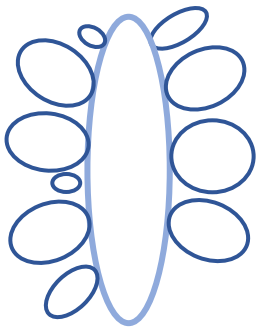


Figure 4A (left): Capsule. Source: (Eva Gjessing 2025); **Figure 4B** (right): Flower. Source: (Eva Gjessing 2025)

Both layouts, The Capsule and The Flower, meet the requirements of large, shared areas and flexible learning spaces. The architects fulfil the requirements differently thus when designing The Capsule floorplan than The Flower. In The Capsule the flexibility is created by the open 'learning-scape' not being subject-related. The students can spread out and take a seat as they wish, and interdisciplinary lessons with more subjects combined can take place within the area. The Flower creates schematical flexibility in subject-based learning spaces as classes of students move from one learning space to the other. The open shared space in the Capsule floor plan is a space that is owned by a year group of students or the whole mid-level department and the assigned mid-level teachers. The central space in The Flower floor plan is shared by different classes and their teachers in a year's grade or a department in addition to the more enclosed learning spaces. Bigger schools' Third Spaces may also be subject-related when the learning spaces are subject-related and clustered around them. Like in American high schools, the students have a locker in the Third Space often placed at the departments' entrance. The Capsule provides flexible use of space within a large, open, non-subject-based common area. The Flower provides schematical flexibility in distributing the more enclosed learning spaces linked to a central shared Third Space.

4.0 TEACHING PRACTICES

It's been analysed how the requirements of text and diagrams in the briefs transform into spatial layouts that can be divided into two models of floorplans. Beneath red arrows illustrate the general movement patterns of the didactical practices that take place in the two floorplan models. In the spatial organisation of The Capsule the teaching in general starts with an introduction on the smartboard in front of the learning stair whereafter the students spread out to pick a seat in the variated 'learning-scape' to do their task of the day alone or in a group. When finishing up the lesson, the teachers gather the students on the learning stair again for a sum-up. The movement

pattern of The Flower floorplan starts contrary with an introduction at the smartboard in the enclosed learning space whereafter the students choose between staying or moving out to do their task in the Third Space to end up gathering again in the enclosed learning for a sum-up (Please see Figure 5).



Figure 5A (left): Capsule. Source: pseudonymized floorplan (Eva Gjessing, 2025); **Figure 5B** (right): Flower. Source: pseudonymized floorplan (Eva Gjessing, 2025).

4.1 Teaching practices of the capsule

> In terms of social space, and of each member of a given society's relation to that space, this cohesion implies a guaranteed level of 'competence' and a specific level of 'performance' (Lefebvre, 2016, p. 33).

Lefebvre explains that a certain social practice will take form in the space which demands of the user a certain performance. In school, architecture creates a culture of practice, movement patterns, rhythms and soundscapes that the students and teachers participate in and present by their use. In these patterns of movement where students divide between learning spaces what happens during the didactical practising in the spaces is according to the teachers a lack of overview. They experience a loss of ability to follow up on the challenged students because they either hide or lose concentration and drift away mentally and physically. Considering Lefebvre's theory, it hereby seems that teachers and some students do not fulfil the 'competencies' required by the school architecture. The performance required fails the student who is not mature and disciplined enough to be responsible for one's learning and to request and wait for the help needed. A teacher in a school with the Capsule floor plan explains:

> The children who may be introverted and a bit reserved are more likely to be out of sight here. But also, the outgoing children who might have a concentration disorder need to know exactly where to sit, and the rooms are just so big and transparent that there is always something that catches your eye. (Teacher, 14 years' experience 2021).

I was told that the teachers discussed this issue as a general problem at the school's weekly staff meeting. When observing this floorplan model, I noticed teachers running from one group of students to the other to assure that all groups were continuously working. I saw students running after teachers who were out of sight and teachers running after students not knowing who had raised their hand first to ask for help. One of the teachers described that because of a lack of overview, the teachers risked passing the same student one after the other to find that they disturbed the student with too much help while missing out on others. Another teacher told me that when introducing new learning content at the staircase it was difficult to know whom of the students understood the tasks and who didn't because of not being able to have eye contact with all 75 students gathered on the stair at a time. It appeared that students are less willing to ask questions and share what they do not understand in larger groups. As a result, the teachers could find out late after leaving the learning stair, that most of the students did not understand the task. Unfortunately, the school architecture with a huge learning stair for the introduction makes a rapid shared repetition of the learning content difficult, as it takes a lot of time to get all students in the different learning zones back on the stair for repetition.

Lotte Hedegaard-Sørensen uses the concept of situated professionalism when writing about teachers' ability to engage and include all students in meaningful learning communities when teaching (Hedegaard-Sørensen & Grumløse, 2016). Situated professionalism requires a good overview of the children to see what is at stake in the different social situations of the students as they work in groups. A teacher explained that although the large group of students is divided between several teachers, it's difficult for the teacher to catch up with all the students that the teacher is responsible for. Things happen: the printer runs out of ink, a conflict between two students arises or the teacher meets a student who has waited too long for help and reaches out for them. Hedegaard-Sorensen describes how the teacher must pay attention to the different social patterns and use of the spatial and material environment

of all students, to orchestrate the best possible learning situation for each of them. Inclusionary teaching must create opportunities for challenged students to participate to be integrated in a learning community. School architecture can support inclusive teaching or hinder it by limiting teacher's ability to do so. In sharp contrast to the visions of the briefs, my interviews with teachers point to the fact that the Capsule floor plan, when examined with Lotte Hedegaard-Sorensen's concepts (Hedegaard-Sørensen, 2021) has a tendency to hinder teachers' practice to be inclusive due to a lack of overview.

4.2 Teaching practices of the flower

The central space of the Flower layout, the Third Space, has room for several classes of students to meet at the learning stair for a joint introduction or to combine learning in the enclosed spaces with physical activity in the Third Space. Thus, the stairwell space also functions as a learning space for many groups of students when working in groups. The Third Space at the same time though is often crossed by classes and students on their way to the school library, to the lockers when going out or to the canteen and back and alike. According to the teachers, this combination of traffic and learning space creates problems for teaching in the space and for the concentration and attention of the students working there. When interviewed, one of the teachers compared the large atrium of the school to the main railway station in Copenhagen. The teacher explained that students at the mid-level are still children and that even adults would find it difficult to absorb new learning content if it were to take place at Copenhagens' Central Station.

> Because even though the learning content is exciting and the student is very interested, the amount of disruption is such that I think you must be very, very strong and clever to be able to learn anything at all in such an environment where all sorts of things are happening around you (Teacher, 11 years' experience 2021).

A teacher explained that it's great to have the opportunity to use the atrium to do a physical learning task with the students up and down the stairs, but that it depends on the mental state of the students and the time of the day whether to do this or not. It's generally difficult for the teachers to maintain an overview when using the Third Space. When some students go out into the Third Space to do their schoolwork, the teacher who teaches the remaining students in the enclosed learning space loses sight of them. Although a teacher moves back and forth between the two learning spaces, it is difficult for the teacher to keep track of the students. The learning spaces are designed for team teaching, but often one of the teachers will take the most challenged students to the quietest corner of the Third Space leaving the other teacher to look after the rest. Sometimes a pedagogue teams up with the teacher to look after students in the Third Space who have had difficulties staying in the enclosed learning space. These students then drift out into the Third Space to take a break. The briefs and the architects describe the students as being given the opportunity for *Legitimized Peripheral Participation* a concept derived from the Theory of Communities of Practice (Lave & Wenger, 1991). Based on my field observations and in the light of Hedegaard-Sorensen's theory, it is questionable if the disengagement from the rest of the classmates benefits the students' opportunities to participate. Observing the didactical practices in the schools I did not see any of the students who had drifted away from a lesson being helped back to participate in a student group work within that lesson. A pedagogue I interviewed argued that it would be better for the relationship between the teacher and the challenged students if the teacher could maintain the student within the learning community of the class. The analysis of the didactical practices in the learning spaces demonstrates that new models of floorplans guided by diagrams and text in briefs of future schools in Denmark 2015-2020 to some extend prevent teachers' overview of their students.

> Man does not live by words alone; all subjects are situated in a space in which they must either recognize themselves or lose themselves, a space which they may both enjoy and modify. In order to accede to this space, individuals (children, adolescents) who are, paradoxically, already within it, must pass tests.' (Lefebvre, 2016, p. 35).

What Lefebvre stresses is the fact, that words in the briefs of school architecture will create abstract imaginations of space, in this case, school culture, that when built will put the users to the test of either recognition or of losing themselves. Students lose themselves if they cannot live up to the school child imagined when the school architecture makes it difficult for teachers to include them in learning communities and to support their focus on the learning content. When challenged students are challenged even more by massive disturbances in the large, shared Third Space they practice and affect the space with actions generated by the feeling of not fitting in. In that case the variation of learning spaces built to suit and include every child seems to have the opposite effect as described in the briefs because it undermines that the teacher provides all students the experience of belonging.

5.0 FURTHER PERSPECTIVES

Based on the conclusions of my analysis, I question the outcome of tenders that hold an architectural school project competition. The discursive and social practices around a school brief seem to produce less inclusion due to abstract ideas that aren't properly grounded in teachers' didactical practices and everyday conditions of the school. My limited research points to positioning and collaboration among stakeholders when planning a school that prevents the voices of the users and the questions raised by architects from being heard. This calls for a debate on the methods and the budget needed to create social sustainability with welfare architecture. My empirical material indicates a discrepancy between the vision and representations of the so-called student-centred school architecture and the practices and lived school space that take place with the spatial organisations of students and teachers in the schools. I therefore suggest further investigation into the impact of scale on the school community when building mega schools and favouring flexibility and students' free choice of seating in large, shared spaces. An important discussion needs to be taken on how to increase teacher's ability to create a sense of care and belonging among students with the school architecture and what part herein ownership to a room plays. With the present political aspirations of an inclusive public school with more practice-oriented learning content and all the subjects in school related to sustainability, a revision of benefits of the classroom and its form and functions are required. I suggest

that budget should be given to complement the classroom with different kinds of learning zones indoor and to create additional green private and semi-private workshop spaces outdoor.

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The Studio: Operative Urban Practice from Research to Speculation

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ABSTRACT: The paper addresses the extra-disciplinarity of cultural-environmental research and design speculation as an area ripe for the critical engagement of globalized architectural education and practice. Students from different disciplines (architecture, planning, urban design, anthropology, engineering, and art) studied ongoing urban and spatial transformations occurring as climactic, socio-political, and economic pressures collide in Northern mega-regions. They focused on understanding architecture and its interdependencies on resources and agencies/institutions within the larger territorial patterns of globalization. Investigations of the spatial, infrastructural, and typological systems emerging from a broad array of interrelated forces--e.g., global finance, industry and trade; digital media/technologies; social discourses; environmental/geophysical phenomena; geo-political strategies--prioritize crises and controversies bearing critically on the role of ethical design. The works demonstrate a more general shift in architectural thinking, one that points to the emergence of what may be articulated as a new operative practice that reengages Manfredo Tafuri's original concept of operative criticism through the engagement of architecture with the contradictions of its capitalist mode of production today.

KEYWORDS: Urbanism, post-disciplinary, globalization, operative criticism

1.0 INTRODUCTION

This paper reviews a paradigm shift towards new understandings of the transformation of the environment through architecture, and its meaning for the education of the architect in terms of representational practices. It revisits Manfredo Tafuri's original framing of an operative criticism engaging architecture with the contradictions of its contemporaneous capitalist mode of production to review the studio as a model of practice relating design and thinking on the larger environmental perspective. Student projects viewed as part of this general shift in architectural thinking are reflected upon and set into their contexts.

The premise is that we can recuperate the notion of environment, or ambiente, from designer and thinker Tomás Maldonado, who, in his book Design Nature and Revolution toward a Critical Ecology (1970), uses the term environment to mean not just nature - but an expanded state in which technology, culture, and global ecosystems might be visualized and modeled as mutually generative processes and forms. Such an integrated notion of environment can be relevant today as we understand the political and ecological systems that mediate our interactions with them.

1.1 Practice

Maldonado's reflections on pedagogy were written during a time of unsettled political struggles. His writing is linked to the rise of 'environment' as a socio-political, technological, and aesthetic category the late-20th century post-WWII era. In architecture, the building up of the concept of environment during this period is predicated on a series of canonic highly exclusive events occurring at the Museum of Modern Art in New York – where, in the members letter entitled "The Museum of Modern Art and the Man-made Environment: An Interim Report," Emilio Ambasz, Curator of Design, launched the museum as a protagonist in contemporary debates on 'environment'. At a time when:

> concurrent with advances in the sciences, the development of a new world-view that conceives of systems as dynamic and in a constant state of change has driven designers away from concern with isolated elements toward a focus on processes

Ambasz sought "new ways of comprehending and acting upon the processes that give form to our present environment." (The Museum of Modern Art 1970) W. Whereas established definitions of design focused on discrete solutions in the form of a building or object created by individual designers, the new designer:

> beholds [the environment] as a result of the processes of interaction I the physical elements he (sic) designs and s'ciety's patterns of rules and behavior. The current changes taking place in design research, practice, and education can be seen, therefore as attemps to develop new design approaches which can deal comprehensively with all factors invIed ... These have greatly expanded two important concepts: first, the notion of what constitutes design and the extent of its relation to the socio-economic environment; and second, the modes by which the designer beholds his environment and the methods by which he attempts to act upon it. (The Museum of Modern Art 1970).[1]

The aim of design would thus be to produce neither a final image or determinate form but rather to facilitate an interdisciplinary framework for continual negotiation that would remain open to contestation and adjustme't. This 'continual ne'otiation' would take place in a new type of educational institution (never achieved) called the University of Design and Development. A two-day MoMA international symposium entitled The Universitas Project: Solutions

for a Post-Technological Society elaborated on a “new type of University concerned with the evaluation and design of our man-ma”e “ilieu"a "self-modifying ethic”l system" predi“ated on "dynamic concept of a complex systemic indeterministic design to operate in a constant state of reform and adaptation to other”systems."[2]

The exhibition Intitled Italy The New Domestic Landscape: Achievements and PrIblems of Italian Design also opened at MoMA in 1972. In the catalog of the exhibition, in“his essay "Design and Technologi”al Utopia," Tafuri ironically lamented th’ architect's lack of agency in face of cybernetic communication systems logics. He argued that the Italian radical architects (Archizoom, Superstudio) had failed in their attempts at institutional transformation and that their the work only threatened to enhance the commercial systems aligned with capitalist forces. (Tafuri 1972).

Yet Tafuri also wanted to recognize that critical engagement could operate neither nostalgically (mythologically) nor through assimilation to market imperatives. Grouping together the Italian radicals with the camps of the American neo-avantgarde emerging with in the 1972 publications of Five Architects and Learning From Las Vegas, he questioned the goals of the resemanticization of arc“itecture: "But what does the recovery of the semantic mean? Why establish, today, such an objective, and of what ultimately must the architec‘ural sig’ 'speak”of' again?" (Tafuri 1972).[3] He sa“ that any "action withou” a subject" left the architect simply a cog in the cybernetic/informational capitalist machine. Tafuri had already clarified that with the decline of the profession there was a correspondi“g lack of "an institutionally d”fined role" for an a“ternative "technology of the wor”ing class." In the preface to his early essay A Critique of Architectural Ideology published in the Italian workers journal Contropiano, he states that the possibility for critique in an unspecified future depends on the demystification of the systems supporting the discipline:

> Reflection of architecture, as a critique of the concret‘ ideolog’ 'realized' by architecture itself, can only push further, and strive for a specifically concrete dimension in which the systematic destruction of the mythologies sustaining its development is only one of the lectives ... But only the future conditions of the class struggle will tell us whether the task we are setting ourselves is that of an avant-garde or a rearguard.(Tafuri 1976)

Tafuri sought to articulate a way for architects to contest the power of capital and to underline the importance of political perspective, and t2aziness2s2the possiblity of an operative criticism. In the preface to Architecture and Utopia: Design and Capitalist Development h“ writes that "the new tasks given to architecture are something besides or beyond architecture. In recognizing Is situation... I am expressing not regret but neither am I making a apoc”lyptic“prophecy," and, "a lucid awareness of the present situat”on is necessary." (Tafuri 1976). His reflections on architectures capacity to maintain a social consciousness within late capitalism are instructive:

> From the criticism of ideology it is necessary to pass on to the analysis of techniques of programming and of the ways in which these techniques affect the vital relationships of production. For those anxiously seeking an operative criticism, I can only respond with an invitation to transform themselves into analysts of some precisely defined economic sector, each with an eye fixed on bringing together capitalist development and the processes of reorganization and consolidation of the working class. (Tafuri 1976)

2.0 PEDAGOGY

New multi-disciplinary pedagogies were developed to addres the relation of built/physical and human/social environments. The fields of including environmental psychology, human behavior, human geography, environmental behav2azines general systtems theory establishe“ a new”focus on "users." The inte“est i” everyday "users" was part of the critique of the top-down, expert-centered professional practice associated with 1950s High Modernism. A number of authors have substantially examined how the process of understanding the environment bec2aziness2s2rative possiblity rather than a predeterimined entity during this time.[4] One of the key figures in the institutionalization of environmental studies and design was Christopher Alexander who founded the Center for Environmental Structure at Berkely in 1967. His writings addressed questions of translation in arriving at environmental form or structure when working from sets of observed data about human behaviors. He writes:

> Forces generate form. In the case of certain simple natural systems this is literally true. In the case of complex man-made systems it is a metaphor. (Cristobal Olave2021).[5]

The first exhibition of Landscape Urbanism in 1997 at Storefront for Art and Architecture in New York City presented new forma 2 aziness 2 sceptual approches for architecture to address the large scale urban and landscape environments. Originating in North American academia, Landscape Urbanism and its extension Ecological Urbanism were intended as alternatives to object-fixated modern(ist) design and traditional urban form that had failed to intervene successfully in the dynamic and complex urban metabolism. Their goal was to shift the focus from architecture to landscape as the organizer of space.In numerous publications landscape is positioned in contrast to architectural design principles like stabi–ity and control - framed as a continuous horizontal field of form that is large- scale, organic, open-ended, adaptive, flexible, and self-regulating in contrast to normative architectural principles of stable form. (Mostafavi and Najle 2004). In contrast to post-war deterministic approaches, Pierre Belanger, one of the main protagonists of the movement, states: ‘(i)n the wake of over-planning, over-regulation and over-engineering of the past century’, future design has to be oriented towards ‘the recoupling, re-configuration, and re- calibration of these processes’, through ‘the re-design of infrastructure.’ (Bélanger 2013a), (Bélanger 2013b). Replacing the rationale of the engineer, Belanger (a PhD in mechanical engineering) aimed to move engineering to urbanism. He endorsed infrast‘ucture that wa’ 'pos‘-euclidian' ’nd 'post-carbon.'

The claims of Landscape Urbanism can be framed by the historical role of engineering in social and technical networks for controlling urbanization processes. Antoine Picon highlights how French engineers had:

> an enduring connection’ with social preoccupations and were somewhat messianic in their approach of technology as well as in their ambition to use it to service society. (Picon 2007).

Examples of mixing social concerns with variables of the biological environment variables include the diagrams of epidemiologist John Snow, whose work on the mortality of cholera in England in the mid-19th century related temperature gradients and water supply systems with urban mortality. (Koch 2'11). Ian McHarg's ecological systems mapping approach to landscape and regional planning at University of Pennsylvania is the predecessor of Landscape Urbanism and Ecological Urbanism. Landscape architect James Corner makes a methodological shift from top-down to bottom-up logics and processes, reacting against the top-down, reductionist and authoritarian practices in engineering and planning to focus design on internal systemic mapping that would uncover spatial and temporal relations. He writes:

> In making visible what is otherwise hidden and inaccessible, maps provide a working table for identifying and reworking polyvalent conditions; their analogous-abstract surfaces enable the accumulation, organization and restructuring of the various strata that comprise an ever-emerging milieu. Mapping differs from 'planning' in that it entails searching, finding and unfolding complex and latent forces in the existing milieu rather than imposing a more-or-less idealized project from on high. (Corner 1999).

2.1 Project

The aim was to educate a generation of designers with capabilities to develop global perspectives and understanding of design in its larger worldly and planetary frameworks. Projects emphasize reciprocity between the local and global pressures acting on images, objects, places, and people. The course addresses the value, role and methods of "research" in the context of design studio and the ability to communicate effectively.

An interest lies understanding how conventions and assumptions of design practice and processes at the urban scale are changing and to begin to clarify what we mean by practice, disciplinary, or research, and consequently how teaching and research methods can have impact and relevance on urban practices and design. Mundane terms like professional and disciplinary imply controlled and regulated approaches. The term urbanism has been used to signify interest in the agency of architecture to affect the larger scale. Some of the issues with urbanism are that urbanism often did not take a systematic approach; had no professional qualifications and was not recognized as discipline.[6]

At Aalto in 2014 I was tasked with studio between the scales of housing design and urban and regional planning. In collaborative discussions we discussed the studio as a place for dialogue on the urban beyond Finnish cities; the need to elaborate the realm of architecture into the urban; and the development of an approach to framing urban design problems in terms of the relationships of culture and environment. The courses were focused on representation across the scales implicated in city making as well as between theory and practice. Questions were about how rethink site program, scale and context to respond to 21st century urbanization and its many forms.

The 5-week studio project addresses the fundamentals of representation; rigorous, explorative research, speculation, and design; and being comfortable working within unknown futures and fields of knowledge. A broader context is given. Students are responsible for addressing site, program, and type of built form and positioning each through the lens of the studio's premise. The studio's work was developed in response to both the vast scale and to the micro-conditions and fabric of contested and often eviscerated landscapes. Collectively the projects in various ways sought to conserve or re-activate the landscape through architectural tactics. The studio engaged landscape architectural methods, urban design methods, planning methods, geographical methods on ecology, environmental science and legal thinking.

The studio considered larger multi-scalar physical social and temporal environments impacted by design actions. Progam and use were used to instigate effects beyond the project itself to bring in questions of transformation, interacting processes, and migrations of knowledge beyond disciplinary silos. Forces due to infrastructural connections, development models, and social agents were considered with their effects that were visible and invisible, physical and non-physical. By thinking about conditions rather than a program, by addressing notions of leverage (or levers that would produce actions) and metabolism instead of construction, and by conceiving of site as an unbounded condition, the students became attuned to environmental dynamics and disparities. They realized that they were already starting to design by focusing on place and culture-specific local conditions, metabolism, and opportunities for leverage opportunities.

The course begins with seminar with an intensive reading and discussion component to open a discussion on a geopolitically cosmopolitan global urbanism. (Authors have included Agamben, Gottman, Hardt and Negri, Foucault, Scott, and others.) The premise is that an intertwined more connected world comprised of local and global accountability at certain moments in time and place can provoke a more critical understanding of archit'cture and design's role in society. The drawings concerned a kind–of deep mapping - drawings that are hybrid–and intelligent - more than 2-D image of places, names, topography. An interweaving of scales, drawing conventions, types of information. If a map is a cartographic abstraction them deep mapping is as much a process of archaeology as cartography. Representation was framed as a key mode of conceptual operation, that how to legibly portray and clearly communicate dynamics that are not just spatial but also temporal and relational entails more than compositional or graphic skill. Rich bio-geopolitical contexts can be settings from which to think about design and environmental change. The hope is that architectural representations and techniques can provide evidence or ways to think about or intersect architecture with environmental conditions, land justice, commons, and property beyond boundaries that are being theorized in other fields such as earth jurisprudence and legal scholarship

As the modernist institution of architecture shifts to an ecological ethos of longevity, maintenance, repair and stewardship, questions of what environmental conditions can be made visible, why should they be visualized and/or experienced; and what are their temporal and scalar implications are important and cand be addressed in the studio

pedagogy that exceeds the buzzwords of sustainability discourse an4azinessce, then hazyness of post-occupancy studies and the 197“s conc”ption of "users."

3.0 STUDENT WORK

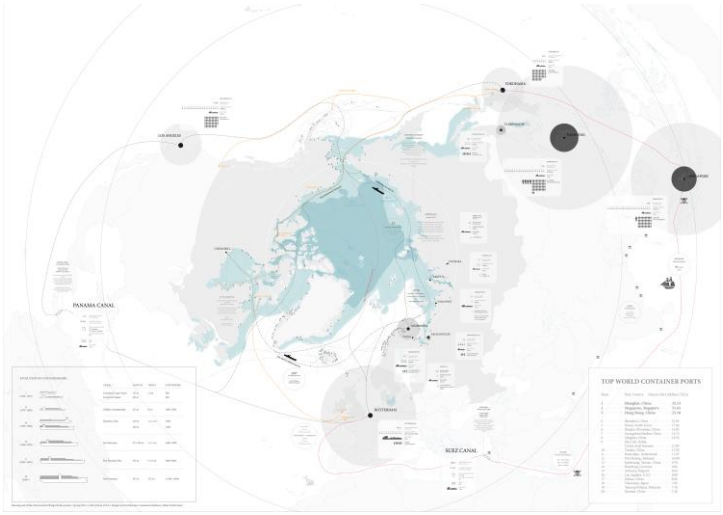


Figure 1: Absolute Arctic. Source: (Anastasia Gluhkova, and Heini Emilia Saari 2014)

3.1 Absolute Arctic (Figure 1)

The project inserts a signal jammer powered by wave energy the vicinity of the North Pole to create a space of disconnection. It’s location is not definite, as it circulates in the ocean with a sea current. All GPS and radio signals are blocked in the area os that the space is invisible and can only be perceived through the lack of signal. The project reintroduces a glimpse of the unknown and unpredictable in the Arctic by reflecting the threshold of an iceberg into the void space of the signal-less area. With GPS, the location of existence is always marked in relation to objects and coordinates. In this project, the passenger taking the risky journey would be in pure nature, absolute Arctic that does not relate or belong to any country and only exists relative to this awareness. Project by Anastasia Gluhkova and Heini Emilia Saari.

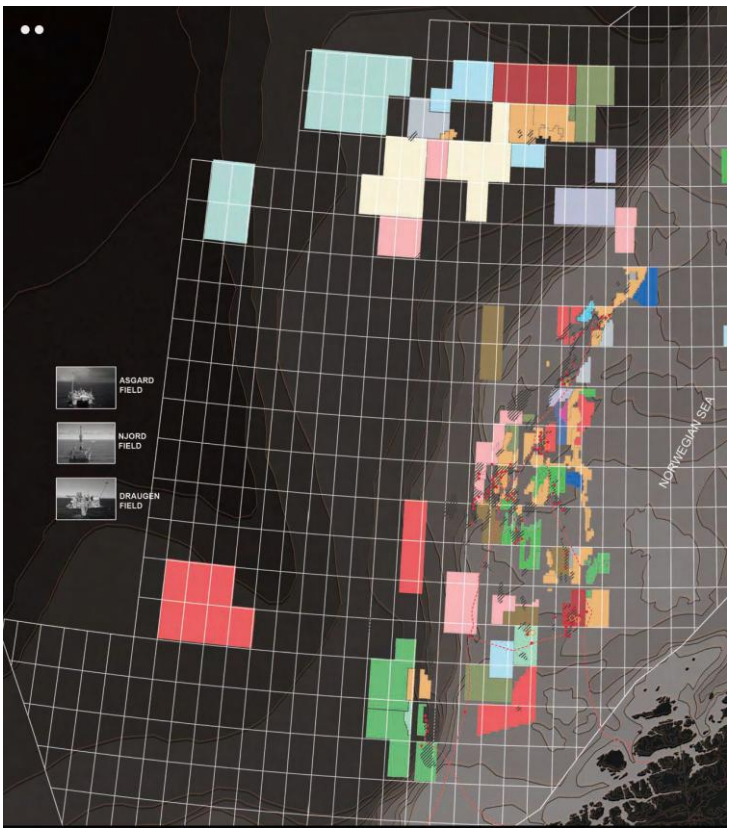


Figure 2: Petro-Urbanisation. Source: (Tommy Degerth and Stefanos Theodorou 2014)

3.2 Petro-urbanisation (Figure 2)

This study compares the intertwining of the oil industry and the education sector in Stavanger, the nominated Energy Capital of Norway the development of Hammerfest, a small fishing town in the Norwegian Arctic. By looking at land in a territorial way you start to see larger patterns of political boundaries and start to think th't design shouldn't focus on just one of these boundaries. Project by Tommy Degerth and Stefanos Theodorou.

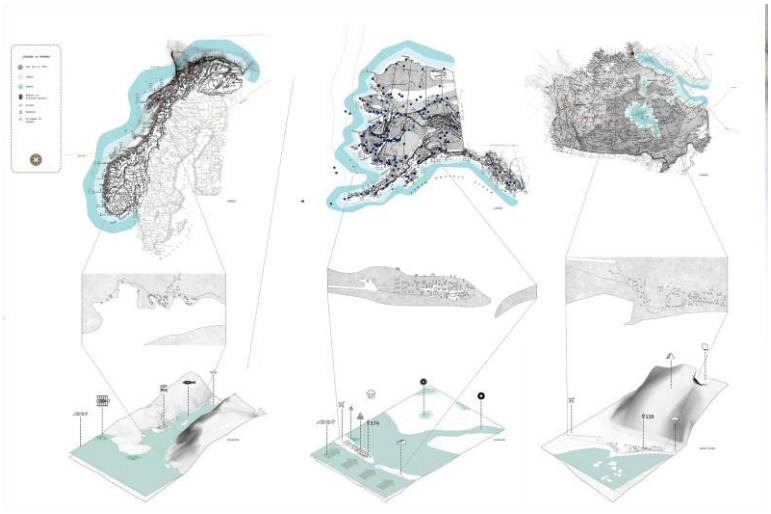


Figure 3: Cryosphere. Source: (Tomas Nordstrom, Daniel Seyfang, Biel Susanna Viladot 2014)

3.3 Cryosphere (Figure 3)

The students collected, combined, and connected the top-down set of changes that are occuring in the cryosphere. They focused on Kivilina, a town that is home to the native Alaskan Iñupiaq community predicted to vanish in by 2025 and as such would be the first town to succumb to sea-level rise. The village situated on a barrier island along Alaska's west coast about 80 miles above the Arctic circle is one of several native coastal villages dealing with accelerated erosion, vanishing sea ice, melting permafrost. "Piece by piece, existing buildings are exchanged for new ones, which will be placed on top of a platform based structure that will be lifted up and float according to the rising waters This small scale project could be the first in an overall operation that would allow us to catalogue multiple solutions and provide all the villages with suitable systems. Project by Tomas Nordstrom, Daniel Seyfang, and Biel Susanna Viladot.

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ENDNOTES

[1] In Architecture and Techno-Utopia, Felicity Scott identifies the emergence of a post-industrial conception of the urban environment - one that is "part of a significantly enlarged territorial scale with a new set of conceptual tools or methods involving systems theory, cybernetics, information theory, and semiology, in which design would be connected to new media formats, materialities and processess, institutional logics, and relations between human subjects, all functioning within larger environmental and technological and information ecologies in a new, human centered worldview." (Scott 2001, 90)

[2] The symposium included philosophers, designers, architects and scientists — including Jean Baudrillard, Umberto Eco, Hannah Arendt, Richard Meier, and Christopher Alexander — who reflected on the new parameters for design in a dynamic interactive world.

[3] "All the intellectual anti-consumer utopias that seek to redress the ethical distortions of the technological world by modifying the system of production or the channels of distribution only reveal the conplete inadequacy of their theories in the face of the actual structure of the capitalist economic cycle."

[4] In architecture programs such as at MIT, University of California Berkeley, University of Texas Austin, Pennsylvania State University, Cambridge University, and Ulm Hochschule fur Gestaltung new academic programs departments of environmental design were founded. See Arindam Dutta, A Second Modernism: MIT Architecture and the Techno-Social Moment (2013); Design on the Edge A Century of Teaching Architecture at the U. of Calif Berkeley 1903-2003, Eds. Waverly Lowell et alia (2009); and Jennifer Light, the Nature of Cities Ecological Visions and the American Urban professions 1920-1960 (2009) as cited in Larry Busbea, The Responsive Environment (Minneapolis: University of Minnesota Press, 2020).

[5] Another example of the form-force interface is Alexander's research with Marvin Mannheim on a stretch of highway in Massachusetts. With a map and tracing paper Alexander and Mann diagrammed (by superimposing photographs, then overlaying diagrams to create a new field of composite forms) the socio-technical forces they believed defined the problem of locating the highway (costs, travel time, noise, drainage...).

[6] In the early- to mid-2010s a resurgence of interest in design at the larger scale design occurred as architecture schools began to offer urbanism programs. At MIT design at the scale larger than the singular object is signified by a degree program in architecture+urbanism. At the Architectural Association the Design Research Lab (DRL) confers a Master of Architecture and Urbanism Degree intersecting architecture with design and engineering. Dissatisfaction with term urbanism was evident in rise of new programs using terms like territorial city or territorial design, or terms like computational urbanism, marking a shift to larger perspectives and to the ostensible non-urban.

FUTURE ARCHITECTURAL EDUCATION

The Intersection of Explored and Unexplored Design Processes with AI Image Generators in Three Design Studios

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ABSTRACT: This study explores possibilities for the integration of artificial intelligence (AI) image generators into architectural education, examining the intersection of traditional design processes and emerging AI technologies. While practitioners increasingly adopt AI in architectural practice, its incorporation in educational settings remains relatively unexplored. The research addresses the question of how to offer students the opportunity to use AI image generators while maintaining essential traditional educational content. The methodology combines the lived experience and the exploratory case study approaches, spanning three semesters. Initial observations revealed student skepticism and resistance, with a controlled integration strategy allowing AI usage only after the initial 3D modeling. Subsequent semesters witnessed increased student acceptance and curiosity, showcasing improved 3D visualization quality while maintaining design integrity. Design charrettes utilizing AI underscored the importance of clear design goals, albeit with occasional deviations from the original concept. The discussion emphasizes the nuanced dynamics between AI-enhanced and traditional approaches, offering guidelines for AI integration. Prohibiting initial AI usage and strategic instructor guidance emerged as effective strategies. The study highlights the need for a balanced integration approach, empowering students with AI tools while preserving core architectural principles. The importance of fundamental visualization skills is underscored, positioning AI as a complementary enhancement rather than a replacement. In conclusion, this research contributes to the discourse on responsible AI integration in architectural education. The controlled integration approach demonstrates improved visualization quality without compromising design integrity. The study encourages educators, practitioners, and policymakers to envision a future where AI enhances foundational skills, fostering a collaborative dialogue on the evolving role of technology in architectural education.

KEYWORDS: AI, design education, architecture, interior architecture

INTRODUCTION

This study explores possibilities for the integration of artificial intelligence (AI) image generators into architectural education, examining the intersection of traditional design processes and emerging AI technologies. The advancement of AI has emerged as a potential catalyst for the redefining of traditional design techniques (Figoli, Mattioli and Rampino 2022). But the potential catalyst in educational settings remains relatively unexplored. It is possible that, in December 2023, a search through a number of academic research portals such as ScienceDirect, MDPI, Sage Journals, Wiley Online Library, Taylor & Francis Online, and other academic research portals using the search phrases "("Interior Design" or "Interior Architecture")" and "Design Process" along with "("AI" or "Artificial Intelligence")" could provide a number of literature pieces that address the potential catalyst in general that can serve as a starting point for this research. In Hanafy (2023), user-centered AI platforms such as DALL-E 2, Midjourney, and Stable Diffusion are introduced. Additionally, the author notes that despite Stable Diffusion's fewer features than DALL-E, it has the fundamental advantage of running locally and providing more training data for the model. Due to these reasons, Stable Diffusion has the best outcomes when it comes to designing architectural cases (Hanafy 2023, 9). Further, the author outlined a number of potential use scenarios per purpose, including ideation, sketches, collages, image combinations, build variants, style variants, construction plans, exterior design, interior design, and creating textures. Among the scenarios outlined, the use cases are not well suited to the three platforms, with the exception of Ideation and Sketches, which are more focused on the early design phases (Hanafy 2023). Other papers also stated that the AI platforms possible uses in the early phase (Bolojan, Vermisso and Yousif 2022; Paananen, Oppenlaender and Visuri 2023; Ploennigs, and Berger 2023a; Ploennigs and Berger 2023b; Seneviratne et al. 2022; Yildirim 2022). It is noted in all of the papers above that the text-to-image process can be used to generate ideas based on text before a visual deliverable is developed. It appears that the notes are consistent with Hanafy's paper, which states that the use of AI in user scenarios is becoming less useful as the design advances. From the background of the notes, it is evident that they were developed based on an understanding of the scenario of each stage of the design process rather than the experience of engaging in the entire process. In other words, it is important to note that not enough research has been conducted on the use of AI throughout the existing entire design process scenarios from the onset to the conclusion of one project, such as evidence-based design (Nussbaumer 2009). Moreover, only one of them based its findings on the research participants, especially students (Paananen, Oppenlaender and Visuri 2023), rather than on the authors' self-study and understanding, which could be different from the users' perspectives in education and practice. In combination with the above, this research focuses on the way in which users, especially students, use AI with existing design processes rather than addressing it from a technology standpoint. It takes place throughout and after the entire design process, from Schematic Design through Construction Documentation, to determine how each user employs

AI. With the purpose, this research asks, “How can architectural education provide students the opportunity to leverage AI image generators based on the existing entire design process?” To address the question, this paper contributes to the ongoing discourse on the integration of AI in architectural education by documenting the experiences of introducing AI image generators into design studios. By combining theoretical frameworks with practical implementation, it aims to shed light on the challenges, successes, and potential future directions for incorporating AI in the educational landscape. As architecture stands at the crossroads of tradition and innovation, this study endeavors to provide insights that can inform educators, practitioners, and policymakers on navigating this dynamic intersection.

1.0 METHODOLOGY

This research is based on the exploratory case study method (Streb 2012). The literature review above indicates that little research has been conducted on how to utilize artificial intelligence, which was confirmed by users throughout the entire project process. An exploratory case study can be useful when precedents are lacking and hypotheses are to be generated empirically (Yin 2017). This exploratory case study examines three upper-level design studios. Constructionism, as developed by Papert (1993), provides the theoretical basis for this study. As per the constructionist perspective, knowledge can be gained more effectively when learners are actively involved in the learning process at every stage. Learning is not merely passively receiving knowledge; rather, it is the process of discovering one's own understanding of the subject matter. Based on Papert's conception of constructionism, learners are engaged in the active construction of learning during the process of making artifacts visible to the world. With constructionism, a study (Papavlasopoulou, Giannakos and Jaccheri 2019) explored children's learning experiences through design-based research (Anderson and Shattuck 2012; Reeves 2006), which is a strategic approach to understanding learning processes involving design, exploration, enactment, evaluation, and redesign.

1.1 Research design

The instructor instructs the students step-by-step to follow the instructions in order to produce results, and then they are asked to describe what they have learned from their experience about using the AI image generator tools as a result of their efforts. The study will be conducted in four steps: the first step will be to prepare and deliver teaching materials; the second step will be for students to implement the materials and submit the results; the third step will be to analyze the results, and the fourth step will be to explore how to utilize the results.

1.2 Material preparation

In this work, the author developed teaching materials based on the references (Bundela 2023), which introduce supportive AI tools in the architectural design process. Initially, developed teaching materials such as course slides for workshops introduced multiple AI software programs, such as Stable Diffusion Github, Midjourney, D5, and others. During this research, new tools have emerged, as well as convergence and integration with multiple Natural Language Processing (NLP) engines. With regard to the stream, the author reformulates the workshop format with the only AI tool "Fabrie." It is based on the Stable Bee NLP engine, which allows designers to have more accurate exploration than with other NLP-based tools (Hanafy 2023). Along with the workshop format course slides, the author also designed a set of templates for students to use. This template has designated areas for 1) original text and images, 2) explored outcomes which are the student's favorites after single or multiple explorations, and 3) prompts which were used for the final exploration. Finally, there was a space at the end of the template to record their experience, especially regarding the extent to which they understood and hypothesized how they would use it in their design process based on what they had learned and used in the previous semesters and activities.

1.3 Research participants

During the last four semesters, from the Fall of 2022 to the Spring of 2024, the workshop has been offered to third, fourth, fifth, and graduate-level students in Architecture, Interior Architecture and Design, and Design Studio programs at the author's school. It is the intention of the studio to be coordinated on the basis of the Evidence-based Design framework and to request students to be involved in the entire process, from predesign research to construction documentation. The author's students have been exposed to the evidence-based design process through the studio or prior to the studio. This is the traditional and existing design process that is taught at the author's school. As the studio moved forward, the author introduced AI tools that were appropriate for the specific phase of the evidence-based design process. For example, text-to-image tools for the research phase, image-to-image tools for design charrette (idea sketching) and physical model phases, both text-to-image and image-to-image tools for color, material, and lighting phases, and artificial intelligence rendering tools during the perspective phase. In addition, there were additional workshops before and after the semester to review and discuss other opportunities based on their previous work. Each time the workshop was introduced, students were asked to produce and submit their outcomes voluntarily in accordance with the workshop guidelines. It was not a grading assignment or material. This was a workshop-type experience.

1.4 Data collection

Following the workshop, the author compiled the students' outcomes into a book that was published afterward. Only the author has access to the contents of the book, which was shared voluntarily by the students with the author. Upon completion of the book, the author uploaded it to an online book publication portal to make it available to the students as well as the public as a form of open-source publishing. It consists of the contents of the book, as well as the original student deliverables, such as their original text and images, their exploration of outcomes and the prompt, and their written descriptions of their experience that were collected in the book. The collected data has

been sorted in order to avoid the possibility of identifying individuals from the data collected. In relation to the figures in this paper, they have been regenerated by the author so that they can be used as figures if needed.

1.5 Data analysis

The author collected both text-based and image-based data without disclosing any personal information. In order to analyze the collected data, the author conducted a thematic analysis (Fereday and Muir-Cochrane 2006), particularly in relation to the written student experiences. This led the author to identify themes that could be used to categorize the data. In accordance with the identified theme, the author coded the data and categorized the outcomes of the students. The author summarized the available ways of incorporating AI technology into the traditional design process and existing design process based on the perspectives of the students at the end of the coding. As a result, the author outlines a possible work process utilizing AI tools based on the existing evidence-based design process.

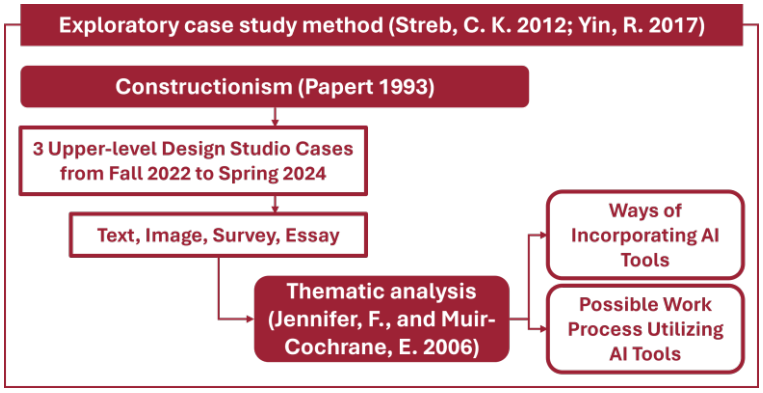


Figure 1: Conceptual Framework. Source: (Author)

2.0 FINDINGS

In the course of exploring AI image generators in architectural education over four semesters, a rich set of outcomes emerged, which shed light on the role of AI in student learning. The findings are organized into three main categories: 1) outcomes produced by students, 2) experience reflected in the outcomes, and 3) conceptualizing a possible design process for architectural education.

2.1 Documentation of the student outcomes

Throughout the past four semesters, AI tools have been introduced in four design studios through workshops. As a result, students from three studios produced and shared their explorations. Fall 2022 was the only semester in which students did not produce AI exploration outcomes. It was an early stage of AI tool development, with DALL-E 2 being released in April 2022 and Mid Journey being released in November 2022. Despite the fact that students explored functions through workshops, no architectural education-related content was explored. In total, 45 students shared their research results over three semesters, except for the semester. Students in the third, fourth, and fifth years of a) Architecture and b) Interior Architecture and Design are participating in this program. These are the results that they shared (Table 1). Student explorations were compiled into three books and published online for the use of students' promotion and portfolios (Figure 2).

Table 1: Collected Students' Explorations. Source: (Park 2023a; Park 2023b; Park 2024)

Data type		*Number of Pieces*
Original Design Deliverables		392 in total
	Text	29
	2D visualization (including graphic design, layout, logo, etc.)	19
	Pictures of physical models, material boards, and reference images	100
	Hand-sketches	92
	3D visualization (perspectives)	152
AI Generated Explorations		642 in total
	Based on the Text	42
	Based on the 2D visualization	31
	Based on the pictures	173
	Based on the hand-sketches	152
	Based on the Perspectives	244
Prompts	*Used for the AI Generated Explorations*	278 in total
Essays	*Describing their experience*	36 in total

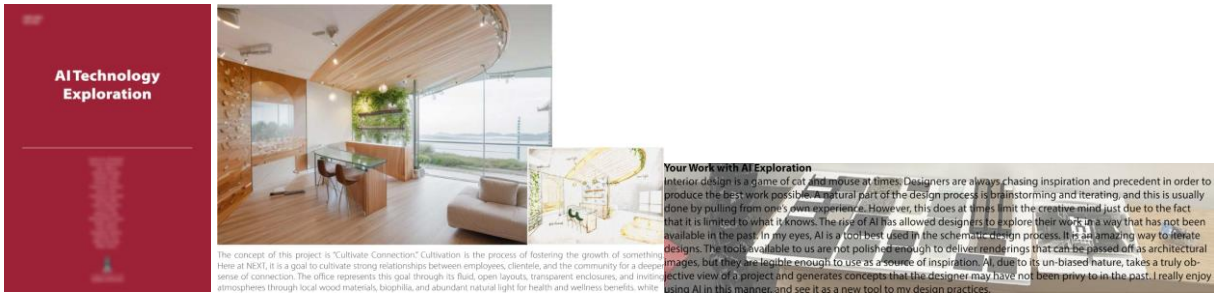


Figure 2: Book (Left) and Collected Data Sample Capture (Middle and Right). Source: (Park 2023b)

2.2 Analysis of the student experience

An analysis of the collected 36 student essays was conducted using the thematic analysis method. There are several recurring themes and perspectives in the essays on AI exploration in the context of design (Table 2).

Table 2: Collected Students' Explorations. Source: (Park 2023a; Park 2023b; Park 2024)

Themes	Summaries
Positive Impact on Design Process	• *Many contributors express a positive impact of AI on the design process, emphasizing its usefulness in generating ideas, exploring materials, and providing quick iterations.* • *AI is seen as a valuable tool for streamlining material selection, enhancing creativity, and offering unique design possibilities.*
Schematic Design Emphasis	• *The majority of contributors highlight the effectiveness of AI in the schematic design phase. It is often described as a helpful tool for brainstorming, ideation, and exploring design options in the early stages.*
Limitations and Realism	• *Several contributors acknowledge the limitations of AI, especially in terms of accurately rendering complex details, handling abstract geometry, and merging elements in the image.* • *The need for post-processing and human touch is emphasized to refine AI-generated images and align them with the designer's vision.*
Material Exploration and Visualization	• *AI is frequently mentioned as a tool for exploring materials, suggesting color palettes, and visualizing different design elements.* • *Contributors appreciate AI's ability to assist in material and color palette decisions, providing inspiration for the overall design.*
Client Interaction and Collaboration	• *The potential for using AI in client interactions is discussed, with suggestions that it can be used to present various design options and involve clients in the decision-making process.*
Educational and Learning Tool	• *AI is recognized as a tool that can aid in learning and education, providing insights into design principles, spatial layouts, and material choices.*
Role in Future Design Practices	• *The essays contemplate the future role of AI in design practices, with some contributors foreseeing its integration as a staple tool for architects and designers.* • *The evolving nature of AI technology is acknowledged, and its potential impact on the design profession is discussed.*
Concerns and Considerations	• *Some contributors express caution about relying too heavily on AI, emphasizing the importance of human creativity and design expertise.* • *There are mentions of AI's current inability to fully understand and interpret complex design projects.*
Efficiency and Time-Saving	• *AI is praised for its ability to speed up the design process, providing quick iterations and ideas in a time-efficient manner.*
Customization and Specificity	• *Contributors highlight the importance of being specific in AI prompts to achieve desired results, and they suggest that customization is crucial for accurate outcomes.*
Artistic and Aesthetic Considerations	• *Discussions include considerations of the aesthetic quality of AI-generated images, including the need for improved clarity in articulating visual elements and refining descriptions.*
Adaptation and Learning Curve	• *Some contributors mention a learning curve when initially using AI tools but express eagerness to adapt and incorporate AI into their design processes.*

There is a strong consensus among students that AI can play a positive role in the design process, emphasizing its usefulness in generating ideas, exploring materials, and providing quick iterations. As a valuable tool for streamlining material selection, enhancing creativity, and offering unique design possibilities, AI can be considered as a valuable tool. A majority of students emphasize the effectiveness of AI during the schematic design phase. Early on in the design process, it is often described as a useful tool for brainstorming, ideation, and exploring design options. There are, however, several students who acknowledge the limitations of AI, especially when it comes to accurately rendering complex details, handling abstract geometry, and merging elements within an image. For AI-generated images to be refined and aligned with the designer's vision, post-processing and human touch are essential. Artificial intelligence is frequently referred to as a tool for experimenting with materials, suggesting color

palettes, and visualizing different design elements. As a result, students appreciate AI's ability to assist in material selection and color palette selection, providing inspiration for the overall design. The use of artificial intelligence in client interactions is discussed, with suggestions that it can be used to present various design options and engage clients in decision-making.

There is a discussion of the future role of AI in design practices in the essays, with some students foreseeing its integration as a staple tool for architects and designers. AI technology is acknowledged as an evolving technology, as well as its potential impact on the design profession. Some students express caution about relying too heavily on artificial intelligence, emphasizing the importance of human creativity and design expertise. There is a mention of AI's inability to fully understand and interpret complex design projects at present. With AI, the design process can be sped up, providing quick iterations and ideas in a timely manner. In order to achieve desired results, authors emphasize the importance of being specific in AI prompts, and they suggest that customization is crucial for obtaining accurate results. AI-generated images are discussed in terms of aesthetic quality, including the need for improved clarity in articulating visual elements and improving descriptions. Many students mention a learning curve when using AI tools, but they are eager to adapt and incorporate AI into their design processes. The essays revealed a variety of perspectives on the use of AI in design, including its potential benefits, limitations, and the evolving role it may play in the future of architecture and interior design.

2.3 Conceptualization of AI integration in the design process

In terms of using AI tools at the current technological level, there are four major phases that can be utilized, as shown in the students' explorations above (2.1) and their experience above (2.2). In the first phase of the project, a series of text-to-image visualizations are created based on the project description or concept statement to illustrate options for implementation (Figure 3). As a second step, you might be able to use a physical model or a reference image as a starting point for exploring possible options based on a model or reference image (Figure 4). On the basis of the hand sketches, you'll be able to explore possible outcomes in the third step (Figure 5). It is possible to explore possible tones of material, finish, color, and lighting during the process of perspective drawing in the fourth phase (Figure 6). As shown in the steps above, these are areas where students have clearly identified the benefits of implementing AI tools in their designs, as indicated in the steps above. Additionally, in cases where dimensional accuracy is required as part of a task, partially usable results are shown. If the above four possible ways of using AI tools are applied to an existing design process, such as evidence-based design, it becomes clear that there are parts that will be utilized from the predesign phase to the design development phase of the design process.



Figure 3: Collected Data Samples for Text to Image. Source: (Park 2024)



Figure 4: Collected Data Sample for Physical Model Picture to Image. Source: (Park 2024)

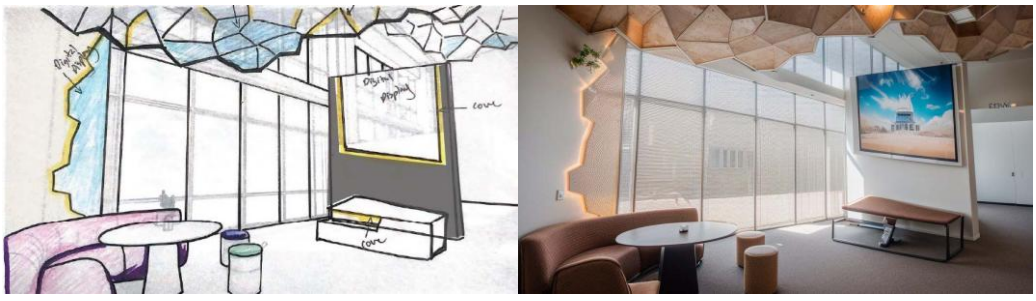


Figure 5: Collected Data Sample for Hand Sketch to Image. Source: (Park, J., 2023b)



Figure 6: Collected Data Sample for Perspective to Image. Source: (Park 2024)

3.0 DISCUSSION

The results of this study illuminate key insights into the intersection of AI image generators and architectural education, paving the way for a thoughtful discussion on their implications and potential directions.

3.1 Overview of student processes and outcomes

The comparison between AI-enhanced and traditional approaches reveals nuanced dynamics. The controlled integration of AI post-initial 3D modeling demonstrated a notable improvement in visualization quality while maintaining the integrity of design elements. However, challenges surfaced as AI-generated images occasionally deviated from the original design concept, indicating the need for strategic guidance to align AI prompts with students' conceptual intents. During design charrettes, AI's role in exploring possible forms underscored its effectiveness when students defined clear design goals. Yet, it also highlighted the importance of fundamental visualization skills, as unsatisfactory outcomes were linked to potential deficiencies in physical and digital models.

3.2 Suggestions for AI integration

Guidelines for incorporating AI in 3D visualization include a phased approach, restricting its use initially and emphasizing its role in enhancing, not dictating, design outcomes. Recommendations for utilizing AI in design charrettes advocate for a clear articulation of design goals and strategic instructor support to bridge the gap between AI-generated outputs and students' original concepts. The findings underscore the need for a balanced integration strategy that empowers students with AI tools while preserving the core principles of architectural education.

In the event that the tolerance range recognized by AI tools differs from the tolerance range recognized by humans, and the degree of understanding of errors differs based on these differences, the importance of basic skills must be reconsidered. The AI tool can, for example, understand and examine a student's work as it exists accurately regardless of whether the cutting skills of a model, the angle of a photograph, or the clarity of a sketch line were not intended, but rather resulted from a lack of basic skills. It appears from the photo below (Figure 7) that the AI, which recognized the result was different from what the student had intended, maintained the chair's form and produced it accordingly. The need for basic implementation capabilities has therefore become increasingly important.



Figure 7: Collected Data Sample. Source: (Park 2023b)

The use of AI tools during the ideation process is possible when using languages during the pre-design stage. A program description for "mind-scapes," for example, is available from the Interior Design Educator Council's Student Competition. As a result of using an AI tool, the following recommendations were made for the use of space based on movement: 1) Reclining or lying down, 2) Sitting in a circle, 3) Cross-legged or lotus positions, 4) Hugging or embracing, 5) Standing tall and open, and 6) Child Pose. Using AI tools, the text-to-image method provides a visual representation of how the actions of individuals would appear in a space. The visualizations are based on actions that correspond to existing typologies of built environments. In light of the author's experience in this process, which was in the preparation of teaching materials, he is confident that AI products will be helpful in the preparation of precedent studies for the analysis of programs.

Furthermore, AI could be directed towards achieving in-depth results when a user or student has a robust and consistent concept statement to his or her own creative works with detailed annotations for each individual design deliverable, as opposed to simply being a tool for exploring possibilities. For example, AI-enhanced 3D visualization

could improve the quality and detail of each image regardless of the prompt, except for human figures. But, it cannot be guaranteed that the improved images are aligned with the original design concept. In contrast, cases where the image was enhanced while maintaining the tone and manner of the space were also noticeable in the students' work (Figure 8). With this process in mind, it appears that when the user has a clear understanding of his or her work expressed in clear language, the existing visualization results may be helpful in determining better results with the assistance of AI.



Figure 8: Collected Data Sample. Source: (Park, J., 2023b)

3.3 Reflection on initial discoveries

The initial discoveries from three semesters of observation emphasize the importance of controlled integration and instructor guidance. Prohibiting AI usage at the outset and restricting it to rendering after 3D modeling emerged as a promising strategy for enhancing visualization without compromising design integrity. Additionally, the study underscores the need for instructors to guide students in effectively using AI prompts, especially during design charrettes, where the alignment of AI-generated outputs with students' design concepts is crucial.

CONCLUSION

The findings and discussions presented in the research paper indicate that integrating AI image generators into architectural education can enhance the design process while preserving core architectural principles. Using AI image generators in three design studios over multiple semesters, this study explored the intersection of traditional design processes and emerging AI technologies.

This research demonstrated that controlled integration of AI, with AI used across all phases but in the development of core ideas itself, resulting in improved visualization quality while maintaining the integrity of the design. AI was initially viewed with skepticism and resistance by students, but over time, their acceptance and curiosity grew. The use of AI in design charrettes led to the identification of the importance of clearly defining design goals, even though some deviations were observed from the original concept.

It was recommended that AI be integrated into architectural education in a phased manner and with strategic instructor guidance. It was determined that prohibiting the use of AI for hand sketches and physical models at the beginning of the design charrettes and then allowing AI to explore possibilities at the end of the charrettes were effective strategies. Throughout this research, the importance of a balanced integration approach is stressed, emphasizing the importance of empowering students with AI tools while emphasizing the importance of basic visualization skills. As opposed to replacing traditional design processes with artificial intelligence, AI was positioned as a complement.

A major contribution of this research is the contribution to the discourse on responsible AI integration in architectural education. Controlled integration improved visualization quality without compromising the integrity of the design. This study encourages educators, practitioners, and policymakers to envision a future in which artificial intelligence enhances foundational skills and fosters a collaborative dialogue on the evolving role of technology in architectural education. In order to validate the optimized design process based on the results of this study, further research is required to explore the application of AI throughout the entire design process.

This paper presents a comprehensive exploration of the intersection between AI image generators and architectural education. The results highlight the potential benefits and challenges associated with the integration of AI tools in 3D visualization, design charrettes, and layout development. The controlled integration approach, observed over three semesters, demonstrated improvements in visualization quality while preserving essential design elements. However, the study also emphasizes the importance of fundamental visualization skills and the need for strategic guidance to maximize the benefits of AI in design education.

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ResThermoVR: Development and Assessment of VR Educational Tool

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ABSTRACT: Understanding building energy simulation poses a significant challenge due to the intricate nature of energy modeling principles, particularly among secondary school students who form the groundwork for addressing climate change. Raising awareness about energy consumption and wastage among students at an early educational stage holds paramount importance for the future environmental well-being. This stems from the fact that individuals commonly encounter difficulty in concretely grasping the extent of their energy usage. This research endeavor seeks to tackle this challenge by conceptualizing and assessing an educational tool in the realm of Virtual Reality (VR) named ResThermoVR. The central objective of ResThermoVR is to augment students' comprehension of diverse aspects, including building thermal behavior, operational and embodied energy of buildings, and the associated carbon footprint linked to environmental consequences. The meticulous development of ResThermoVR from the ground up aligns with the goals and aims of this study. It introduces a distinct VR environment that facilitates interaction with nine distinct simulation scenarios. These scenarios encompass a variety of factors influencing building performance, ranging from alterations in architectural design to modifications in construction materials. This prototype stands as an inventive pedagogical medium, plunging students into the intricacies of a building's energy usage and its ecological consequence. The immersive and captivating nature of this experience contributes to expounding complex concepts. The primary purpose of the prototype development revolves around exploring the high school architecture courses curriculums for refining the prototype with focus of delivering appropriate content for students' study which will assist the subsequent assessments, and evaluations of the prototype.

KEYWORDS: VR Simulation, VR Building Simulation, VR Energy, VR Education, VR Architectural Education

INTRODUCTION

There is a growing imperative to address the repercussions of climate change from an early phase of a student's educational journey. Secondary schools hold paramount significance as a channel for instilling in students a profound comprehension and awareness of key aspects, such as building thermal behavior, energy consumption, and environmental impact. There exists a pressing necessity to heighten consumer consciousness concerning energy utilization and waste. Often, individuals lack the mental capacity to envision the extent of their energy consumption (Haefner et al. 2014).

The far-reaching impacts of climate change are manifesting in the form of devastating natural catastrophes. As reported by the International Energy Agency (IEA) in 2020, buildings contribute to nearly 38% of the annual worldwide CO2 emissions. This contribution can be broken down into 28% stemming from building operations and an additional 10% attributed to building materials and construction, also referred to as embodied carbon (United Nations Environment Programme 2020). Consequently, energy-related carbon emissions in industrialized nations account for 36% of their total emissions (Metz et al. 2007). The escalating demands for energy are driven by a rapid rise in living standards and population growth (Hafeznia et al. 2017). Despite the widespread use of electrical energy to power various elements within buildings, energy remains an often overlooked and misunderstood aspect of construction. Unlike tangible components, energy lacks a physical presence, rendering its conservation less conspicuous. Notably, a substantial portion of a building's overall energy consumption can be attributed to the climate control processes required to meet occupants' desired thermal conditions ("U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," n.d.). Given these circumstances, a transformative shift in energy management, with a primary focus on enhancing the energy efficiency of buildings, should stand as a paramount objective for future generations, both from economic and environmental standpoints (Lin et al. 2016).

In the building industry, concerted efforts are underway to minimize the life cycle energy (LCE) of structures, aimed at reducing their carbon footprint and mitigating adverse environmental impacts (Paleari, Lavagna, and Campioli 2013; Monteiro, Fernandez, and Freire 2016). The entirety of a building's life cycle energy can be categorized into two primary components: embodied energy and operating energy. Embodied energy denotes the energy expended during various stages, including raw material extraction, product manufacturing, transportation, on-site construction, fabrication, life cycle repair and maintenance, as well as eventual renovation and demolition processes (Manish K. Dixit 2017; Manish Kumar Dixit et al. 2010; Hernandez and Kenny 2011). On the other hand, operating energy encompasses the total energy consumption associated with the day-to-day operation of the building, including measures taken to maintain thermal comfort and uphold the indoor environment (Karimpour et al. 2014; Thormark 2002). This aspect can also be referred to as building consumption and usage within the context of this study.

1.0. WHY VIRTUAL REALITY...!

The intricacies of energy modeling principles, the diverse array of factors influencing the outcomes, and the interrelatedness and correlations among these components render building energy simulation a complex concept to grasp (Clarke 2007). Therefore, effectively imparting this level of information to high school students through conventional educational methods presents a considerable challenge. The term "embodiment" refers to "the identification of an abstract idea with a physical entity" (MacLachlan 2004). It can also be understood "the enactment of knowledge and concepts through the activity of our bodies." (Sawyer 2005). Embracing embodiment involves integrating physical, biological, phenomenological, and experiential aspects, giving rise to a unified body-mind perspective that encompasses cognition, actions, and interactions (Hocking, Haskell, and Linds 2001). The interactions between the human body and its physical environment form the basis for human cognition (Gallagher 2006; Wilson 2002). Within the interdisciplinary framework of embodied learning, which consolidates phenomenology and cognitive sciences, it has been demonstrated that cognition is inherently connected to the body and intricately linked to the interplay between perception and action (Varela, Thompson, and Rosch 1993; Clark 2008). Embodied learning breaks down and erases the traditional hierarchy between the brain and the body, as it emphasizes the vital role the body plays in meaning construction and creative processes (MacLachlan 2004).

The current literature across various fields of study, such as linguistics (Lakoff and Johnson 2008), neuroscience and mirror neurons (Decety and Grèzes 2006), mathematics (Noice and Noice 2006), cognitive psychology (Glenberg 2010), and social psychology (Niedenthal et al. 2005), strongly supports the notion that embodiment plays a pivotal role in cognition. From physical and intellectual development to the composition of creative artifacts and engagement in social and emotional contexts, learning processes encompass a diverse range of human actions and mental mechanisms that can benefit from an embodied learning environment (Lindgren and Johnson-Glenberg 2013). The physical embodiment forms the fundamental underpinning of all cognitive learning processes, including the development and comprehension of concepts. Immersive technologies facilitate the type of interaction essential for an embodied learning environment (Lindgren and Johnson-Glenberg 2013; Alhazzaa, Dixit, and Yan 2023). Virtual reality (VR) technologies have the potential to create controlled environments that enable users to physically interact with content and systems. This immersive setting can serve as a platform for exploring and articulating both fundamental and advanced ideas (Lindgren and Johnson-Glenberg 2013).

1.1. VR in education

The Immersive Virtual Reality Learning Environment (IVRLE) offers a sophisticated 3D representation, real-time motion tracking, natural navigation and communication, immediate control, as well as personalized and repetitive learning experiences (Tacgin 2020). This approach shows promise in enhancing education through various means, such as providing multiple viewpoints, facilitating situational learning, and promoting knowledge transfer (Dede 2009). By employing IVRLE, learners' sense of presence is positively impacted, leading to overall improvements in learning achievements (Dalgarno and Lee 2010; Lenz et al. 2015). The potential applications of VRLEs are diverse and include simulating costly and time-consuming safety training exercises (Andersen et al. 2020; Jung and Ahn 2018; Buttussi and Chittaro 2017), conducting field tests in STEM subjects that may pose risks in real-world scenarios (Bennett and Saunders 2019; Lynch and Ghergulescu 2017), and enabling the exploration of three-dimensional (3D) models from multiple perspectives, a feat not easily attainable on 2D monitors (Doak et al. 2020; Zinchenko et al. 2020). The utilization of VRLEs has demonstrated positive effects on student motivation and engagement in the classroom (Buttussi and Chittaro 2017; Olmos-Raya et al. 2018; Stepan et al. 2017). Researchers have also observed that students exhibit increased focus while using VRLEs, which subsequently contributes to improved academic performance and knowledge retention (Alhalabi 2016; Krokos, Plaisant, and Varshney 2019; Kwon 2019).

2.0. PROJECT DEVELOPMENT

This research centers on the conception of an educational VR tool aimed at augmenting students' comprehension of building thermal behavior, energy consumption, and environmental impact. The study encompasses two primary phases. The initial stage involves the meticulous development of a VR environment, tailored to attain the research objectives and goals. The subsequent phase involves demonstrating the proposed prototype to teachers showing how VR technology can be effectively used as an educational tool for complex topics, encouraging its future adoption.

2.1. ResThermoVR prototype

The ResThermoVR application utilizes a diverse array of platforms and software technologies. Figure 1 illustrates the entire development process, which starts with the creation and construction of a 3D model of the building. To construct the energy model, the study employs Grasshopper - Ladybug tools and the EnergyPlus simulation engine, integrated with the Rhinoceros 3D software interface and its Grasshopper visual programming extension. The integration of materials and textures for the production of a VR experience is facilitated in this research through the utilization of Rhinoceros 3D. The central platform utilized for VR content creation is the Unity game engine, which effectively handles both asset generation and the user interface. Particular emphasis is placed on verifying compatibility with the well-known Meta Quest 2 VR headset throughout the development process, as it is widely recognized for its standalone functionalities and superior adaptability. At present, the Meta Quest 2 VR headset ranks among the most financially viable choices within the VR market.

Rhinoceros 3D	Preparing of the building 3D model
Grasshopper - Ladybug tools	Creating the energy model and running the energy simulations
Rhinoceros 3D	- Appling Materials and texturing on the building 3D model - Adding fornitures
Unity Gaming Engine	- Developing VR experince for Meta Quest 2 - Implementing UI and combining assets
VR Device	Visualizing the final combination of building 3D model and simulations outcomes of the study space in the Meta Quest 2 device.

Figure 1. The development workflow. Source: (Alhazzaa 2024)

The VR experience occurs within a digitally simulated traditional American house, featuring two bedrooms and two bathrooms, as illustrated in the floor plan (Figure 2), spanning an area of 110.78 m^2 (1192.43 ft^2). The construction of the digital representation encompasses various aspects, including the layout and arrangement of furniture, the specific furniture types utilized, the physical attributes, and textures, along with the external surroundings (Figure 3). As a result, users can establish a stronger emotional connection to the environment owing to the familiarity of the design and style of the space.



Figure 2. Floor plan. Source: (Alhazzaa 2024)



Figure 3. Interior picture of the VR environment base case living room and bedroom. Source: (Alhazzaa 2024)

2.1.1. Energy simulation setup & scenarios

The ResThermoVR simulation's baseline conforms to the guidelines set forth by The International Energy Conservation Code (IECC) 2006, which has been adopted by the City of Houston, specifically concerning the thermal properties of building materials (City of Houston 2022). The base case entails a wooden framed wall with a thermal resistance of 2.876 m^2K/W (16.329 $Ft^2 \cdot °F \cdot h/BTU$) and a single window with a U-factor of 2.120 $W/m^2 \cdot K$ (0.373 $BTU/h \cdot ft^2 \cdot °F$). The Window to Wall Ratio (WWR) for the base case is approximately 20%. The calculation of WWR is focused on the living and main bedroom spaces, as these areas have been subjected to comprehensive

thermal analysis and visualization as part of the overall building energy simulation. These two spaces exhibit distinctive characteristics attributed to differences in their orientation and usage. The thermal properties of the materials employed in this building simulation are sourced from EnergyPlus materials library. ResThermoVR offers users a platform to engage with nine alternative simulation scenarios. These scenarios encompass a wide array of conditions that can influence building performance, including aspects such as manipulation of building geometry (figure 4 shows the building orientation and figure 5 illustrates the window to wall ratio) and utilization of diverse construction materials. The nine simulation scenarios are as follows:

- 90 Degree Rotation
  - Walls and windows are all constructed with the base case materials, but the building's orientation changed by 90 degrees clockwise.
- 180 Degree Rotation
  - Walls and windows are all constructed with the base case materials, but the building's orientation changed by 180 degrees clockwise.
- 270 Degree Rotation
  - Walls and windows are all constructed with the base case materials, but the building's orientation changed by 270 degrees clockwise.
- Exterior Walls R 23
  - Walls are made with wooden framed construction that has with 3.932 m^2K/W (22.329 $Ft^2 \cdot °F \cdot h/BTU$) R-value. The windows are made with base case materials.
- Exterior Walls R 32
  - Walls are made with wooden framed construction that has with 5.517 m^2K/W (31.329 $Ft^2 \cdot °F \cdot h/BTU$) R-value. The windows are made with base case materials.
- Double Glass U 0.24
  - The windows are made with double glass window assembly that has 1.362 $W/m^2 \cdot K$ (0.239 $BTU/h \cdot ft^2 \cdot °F$) U factor. Walls are made with base case materials.
- Triple Glass U 0.19
  - The windows are made with triple glass window assembly that has 1.224 $W/m^2 \cdot K$ (0.215 $BTU/h \cdot ft^2 \cdot °F$) U factor. Walls are made with base case materials.
- WWR 40%
  - Walls and windows are all constructed with the base case materials, but the building's WWR increased to 40%.
- WWR 60%
  - Walls and windows are all constructed with base case materials, but the building's WWR increased to 60%.

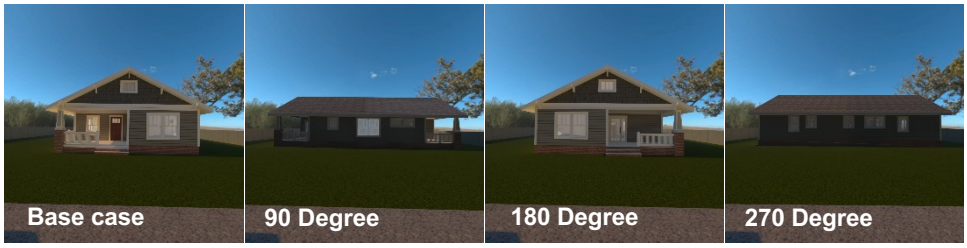


Figure 4. Building orientation simulation alterations that has 360 Degree rotation. Source: (Alhazzaa 2024)



Figure 5. Window to wall ratio design alterations which range from about 17-20% in the base case to 60%. Source: (Alhazzaa 2024)

ResThermoVR generates a comprehensive set of eleven simulation results for each simulation condition which are as follows:
Building Operational energy consumption
Embodied energy (Associated with building materials construction)

Embodied Carbon (Associated with building materials construction)
Summer – interior wall temperature map
Summer – Energy Flow
Summer – Vertical map
Summer – Volumetric map
Winter – interior wall temperature map
Winter – Energy Flow
Winter – Vertical map
Winter – Volumetric map

The computation of the building's operational energy consumption relies on the aggregate yearly energy consumption, with reference to the meteorological data specific to Houston, Texas (EnergyPlus, n.d.). The summer simulation includes the months of June, July, and August, while the winter simulation comprises December, January, and February. The interior wall temperatures correspond to the surface temperatures of the inner layer of walls, which have been effectively visualized using individualized single surfaces. The Energy Flow refers to the quantified energy transfer measured in kWh/m^2 from the external to internal regions of the building, which has been visually rendered through colored surfaces signifying the magnitude of energy flow across each wall. The vertical interior temperature maps consist of an array of 216 sensors strategically positioned within the living room, arranged in a vertical stack to form a continuous surface. In contrast, the volumetric interior temperature maps comprise 250 sensors within the living room and 72 sensors within the bedroom, evenly distributed throughout the respective spaces. Each sensor in these maps is graphically represented by a distinct box, visually floating in its designated location within the room. The calculation of indoor temperature employs the Ladybug plugin integrated with the Grasshopper spatial thermal map tool, employing a combination of three spatial thermal map simulation methods (Webb 2012; Brandan and Alejandra 2012; Arens et al. 2015). Extensive validation of the Ladybug simulation method has demonstrated its reliability, exhibiting a satisfactory level of consistency when compared to both ENVI-met software and field measurements (Ibrahim, Kershaw, and Shepherd 2020; Elwy et al. 2018). As for the simulation of energy consumption and walls' temperatures, the EnergyPlus engine is utilized. To provide data on embodied energy and carbon, a specialized economic model known as an input-output-based hybrid (IOH) macroeconomic model, tailored specifically to the United States economy, serves as the data source (M. Dixit, Culp, and Fernandez-Solis 2015; Venkatraj et al. 2020; Kumar, Venkatraj, and Dixit 2022).

2.1.2. User interface (UI)

The UI in VR possesses a distinctive characteristic wherein it lacks constraints on display size (Bastug et al. 2017). This attribute allows for unparalleled flexibility in presenting information from various directions. While the capacity to showcase abundant content within the VR environment is advantageous, it is equally imperative to ensure that spatial relationships between elements and the user are effectively delineated to achieve optimal legibility and comprehension. In the context of virtual reality (VR), the presentation distance of text carries equal significance to the font size of individual characters. At Google IO 2017, engineers from Google introduced the concept of the distance-independent millimeter (dmm), which serves as a novel unit for gauging perceived size in VR. Specifically, dmm represents a character with a height of 1 mm when situated at a distance of 1 m. To ensure legibility and user comfort, the ResThermoVR UI is designed based on the dmm standard. ResThermoVR incorporates two distinct user interfaces. The primary UI (Figure 6) remains anchored to the user's head, enabling users to observe the interface from various vantage points while maintaining an appropriate distance between the UI and the user. On the other hand, the secondary UI, located on the left controller (Figure 7), serves merely as an information display and is not interactable by the user. This secondary UI is conveniently attached to the user's hand, facilitating easy access for reading, analyzing, and correlating the visualized components represented by distinct colors with their relevant data.



Figure 6. Main UI. Source: (Alhazzaa 2024)

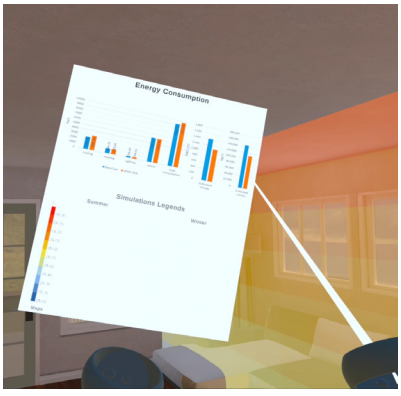


Figure 7. Secondary display mounted to left controller, Energy Consumption Graph, and maps' legend. Source: (Alhazzaa 2024)

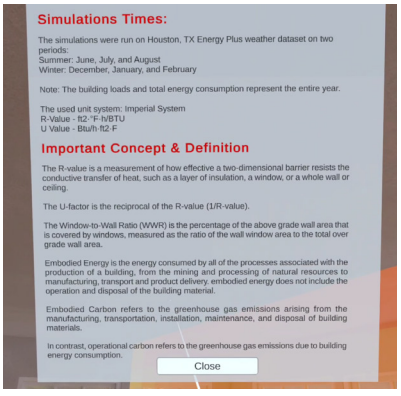


Figure 8. General info panel. Source: (Alhazzaa 2024)

The primary UI comprises three integral components. Firstly, the "General Info" button serves as the initial component, granting access to a window containing informative descriptions of key terms such as "R-Value," "solar heat gain coefficient," "embodied energy," "embodied carbon," and "simulation time" (Figure 8). Secondly, the UI incorporates simulation scenario toggles (as shown in Figure 6). Each condition toggle is linked to an energy consumption graph that presents comprehensive data, including overall energy consumption, embodied energy,

embodied carbon, cooling load, heating load, and a comparative analysis of the existing conditions (Figure 7). Furthermore, the thermal map menu, shown in Figure 6, plays a central role in the UI. This menu includes two submenus, namely, the summer and winter simulation periods. Within each simulation period, four distinct options are available: vertical maps (Figure 9), volumetric maps (Figure 10), wall temperature (Figure 11), and energy flow (Figure 12). Upon selecting any of these options, the corresponding color legend is activated on the secondary display (Figure 7). Lastly, the fourth component of the primary UI enables users to control the transparency of the map's colors, affording them the ability to fine-tune transparency levels and facilitate improved differentiation of individual color tones.



Figure 9. The existing condition vertical map. Note: The same visualization is applied for all simulation conditions. Source: (Alhazzaa 2024)

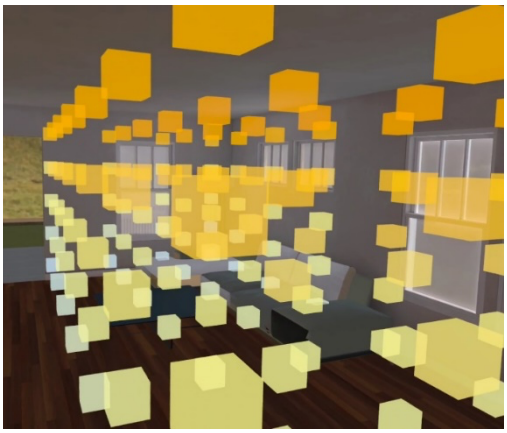


Figure 10. The existing condition volumetric map. Source: (Alhazzaa 2024)



Figure 11. The existing condition wall temperatures. Source: (Alhazzaa 2024)



Figure 12. The existing condition energy flow. Source: (Alhazzaa 2024)

2.2. Prototype demonstration

The prototype was Demonstrated to high school teachers who teach architecture courses through a guest lecture on energy consumption in the built environment. The lecture sequence was methodically organized, starting with a presentation demonstrating fundamental principles and facts concerning embodied energy, carbon footprint, and operational energy within buildings. This presentation also underscored the role of building design and material choices in global energy consumption and climate change, spanning a duration of approximately 30 to 45 minutes. Following the presentation, teachers were offered the opportunity to engage with the presented topic in a VR environment. By immersing themselves in the VR scenario, they could visually grasp the concepts discussed during the presentation. This approach facilitated comprehension by enabling teachers to interact physically with the subject matter, as it effectively translated the lecture concepts into tangible visualizations within an immersive environment.

CONCLUSION & FUTURE WORK

The effectiveness of VR for energy simulation and visualization is demonstrated through ResThermoVR, which transforms abstract energy data into comprehensible visual outputs. By linking simulation outcomes to real-world scenarios, it enhances users' understanding of building operations, including embodied energy and carbon impacts throughout the building lifecycle. The VR environment integrates construction materials, geometry, and orientation, allowing users to explore how these factors influence energy performance. Visual tools like spatial thermal maps and color-coded temperature depictions help users intuitively grasp the relationship between design inputs and energy outputs, addressing common learning challenges. A subset of numerical data is presented alongside these visuals to bridge qualitative insights with quantitative outcomes.

Future development will include expanded features and refined visualizations tailored to high school curricula. After successful feedback from teachers, a more comprehensive study with students will evaluate the prototype's impact on learning, engagement, and retention of key energy concepts.

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Expanding Protocols: Teaching Construction Through Immersive Virtual Learning Environments

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ABSTRACT: Extended Realities or XR has become an increased field of interest over the last decade. It is more accessible than ever, becoming an everyday component found in our homes, businesses and even our education. While there is still a lot of skepticism around the value of this technology, curiosity by many has allowed for different disciplines to embrace it. Its novelty has instigated new questions and spawned new methods of engagement. This paper discusses the use of this technology and documents the development of a proprietary virtual reality application. The application is used as a supplemental tool for teaching an introduction to construction course. Over a three-year period it was tested with different groups students to better understand their acceptance of the technology and ask if it had a meaningful impact on knowledge building related to the subject. It concludes by presenting the qualitative analysis, providing suggestions for how it should be understood and makes projections for next steps.

KEYWORDS: extended reality, education, construction, architecture

INTRODUCTION

As architects and educators, we have a role that requires us to transmit ideas, concepts, and knowledge through different mediums. The use of visual and physical mediums as representational examples is crucial in enhancing the process of understanding. While tried and tested methods of educating are still valuable, alternative methods of knowledge building stimulated experience, simulation and emulation are possible through advancements in technology. New innovations in the tech industry are constantly reinventing workflows for how we educate, communicate, and share information. According to Mario Carpo, “what matters is not so much what digital technologies can do, but what we could not do without them.”(Carpo 2023) To illustrate this, the paper discusses the enhancements and outcomes resulting from a shift in the teaching methodology for an introduction to construction course through the implementation of extended reality (XR). Spanning five years, an introduction to construction course at the University of Michigan has developed and gradually introduced extended reality applications as a supplemental learning experience for students. Reflecting on the complexity of building layers, this course explores the use of XR technology to enable students to become proficient in interpreting, synthesizing, and making two-dimensional representations to produce three-dimensional components.

This experimental method of teaching was tested against the original pedagogical framework that relied heavily on the presentation of construction systems through precedent. The existing course presents concepts and theory through textbooks, short videos, slides, readings or drawing examples and evaluates students using exams and graphic documentation exercises. Within this learning process, the understanding of scale, physical constraints and a grasp of visuospatial reasoning and relationships can be easily misinterpreted. As a result, rather than learning the student is left frustrated leading to a reduced level of comprehension. Recognizing these as areas for improvement raised the question about how knowledge building can be enhanced via extended realities. Do the visio-spatial capabilities of XR afford students an alternative means to comprehend and synthesize content? And second, how should that alternative reality be designed from an experience learning perspective for architectural education?

1.0 PEDAGOGICAL FRAMEWORK

1.1 Arch 317/417 Construction

The course is a requirement for two groups of students of architecture: undergraduates in their third year of a four-year program and master students with a non-architecture background in their first year. The residential course presents an overview of the materials, components and systems of construction that reveal the links between the ideation, elaboration, and realization of architectural form. Lectures are given weekly and cover topics such as an introduction to construction, technical documentation, material systems including masonry, concrete, wood, steel and glass, and their relationship to building elements including floors, roofs, walls, columns, and apertures as well as a brief overview of opportunities for integration towards environmental sensitivity and building performance. To complement the in-depth explanation of the material, lectures also take a detailed look at case studies that exemplify those construction systems. Parallel to the lectures, the lab portion of this course works through a series of exercises that take the subject matter through drawing, analysis, and discussion. These lab assignments reinforce the lectures by asking the student to actively consider and engage in the acts of making as they relate to the role of architectural construction in a historical and theoretical context and locate construction practices within the realm of integration and innovation. Lab exercises as well as weekly interactive challenges require students to demonstrate their

understanding of construction practices and their application. Overall, the goal of the course, as structured through lectures, labs and quizzes, is to provide the knowledge, understanding and ability to work with construction systems as an interrelated and influential aspect of architectural design.

1.2. On-site experience in an academic context

Within a pedagogical framework, the teaching of concept is the primary approach to learning, while the application of these concepts often is left to real life experience which in many cases only occurs after a student has left the classroom and begins to work in the field. While there are many approaches to how one might teach construction, this course focuses on teaching students about construction systems and construction drawing/detail literacy.

Historically, architectural plans and drawings have required a trained eye to interpret and synthesize a series of two-dimensional representations to produce three-dimensional constructs. In his essay, 'The Developed Surface', Robin Evans describes the architect's field of visibility in drawings. "It makes it possible to see some things more clearly by suppressing other things…. Its power to represent is always partial, always more or less abstract. It never gives, nor can it give, a total picture of a project." (Evans 1986) The introduction of 3D modeling has effectively challenged this thinking by producing a more complete spatial representation of the reality without the need for the two-dimensional abstraction. However, within this process the understanding of scale and in some cases physical constraints are easily overlooked by an untrained individual. Reflecting on these methods of representation in an academic setting began to raise questions about the introduction immersive and hands-on methods of learning within a construction course. To supplement lectures and lab, initiatives to take students to active construction sites, host workshops with local construction trades and the introduction of digital technologies that would aid in the workflow of assignments as well as aid in the visualization of the course content was introduced. While these strategies presented challenges, the ability to provide students with on-site construction visits proved to be the most difficult. Due to liability and available opportunity, the integration of an on-site immersive construction experience within the classroom is many times unattainable.

In this scenario it is important to consider how technologies might be of aide and determine which technology might be the most appropriate. According to Jeremy Bailenson, director of the Virtual Human Interaction Lab at Stanford University, you must first ask the question, "what VR is good for?" To determine this, he uses the DICE framework which describes four scenarios: Dangerous, Impossible, Counterproductive or Expensive. Considering both dangerous and impossible as recuring scenarios, the course began to study alternative models and technology that would be less restrictive while allowing for a simulation of the experience of a construction site. This resulted in adapting extended realities, and specifically virtual reality, as a testing ground to understand, translate, and develop new possibilities for the integration of an "on-site" experience through an immersive environment for students.

1.3. What is XR and how can it be used in a school of architecture?

Extended reality (XR) is a term used to describe a fusion of all the realities, which are "… technology-mediated experiences enabled via a wide spectrum of hardware and software, including sensory interfaces, applications, and infrastructure". (XRSI, n.d.). XR includes virtual, augmented, and mixed reality as defined by Milgram et al. (1994) in which he describes a continuum between the real world and the completely virtual world. Progression along the continuum incorporates more digital content overlying the real environment until you reach the point where it is entirely digital. Each of these technologies has its own unique use in both education and real-world applications. Frameworks to guide the use of XR in teaching include both educational frameworks (mastery learning or experiential learning) and user-centered design (Salcedo et al. 2022). It is a technology that also affords new possibilities for collaboration, co-design/co-creation. XR in architecture is used in many ways in a professional capacity, including the design of spaces and new methods of fabrication through human-computer interaction (HCI). In addition, it is being used as an educational tool that goes beyond merely visualizing content by allowing for an embodied and simulated tangible experience with material.

2.0 DEVELOPING IMMERSIVE VISUALIZATION FOR CONSTRUCTION

2.1. Virtual Reality Prototype

Reflecting on the past methods for spatial visualization in architecture, combined with the need to supplement specific learning scenarios that were sometimes unattainable, the course began to explore alternative methods for visualizing course content. To begin to test out ideas the course was awarded funding through the Center for Research on Learning and Teaching, to develop a working prototype that leveraged virtual reality as a learning tool in the classroom. This initial immersive scene was paired with the lecture content on steel construction and a sophisticated but simple precedent that used steel as the primary method of construction, the Farnsworth House by Mies Van der Rohe.

The prototype used the computer modeling software Rhino 3D to create content that was later assembled in the Unity game engine. The Unity game engine provided a platform to integrate the 3D content and interactions with that content using the Oculus (Meta Quest) virtual reality head mounted display (HMD). This became the HMD of choice due to its cost effectiveness, availability in labs across campus, as well as the availability of the Oculus Integration Package in Unity. This package facilitated the use of prebuilt scripts and interactions that reduced the need to customize code to create desired interactions and navigation.

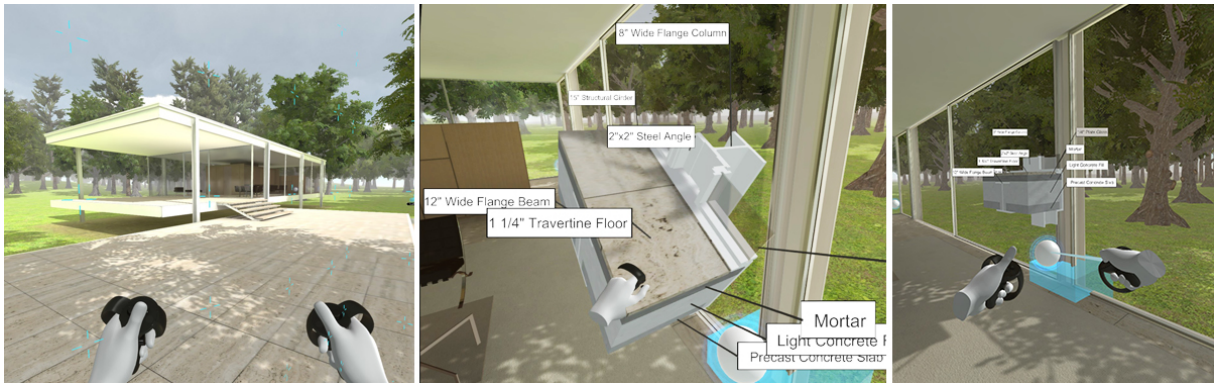


Figure 1: VR Prototype scene using the Farnsworth House. Source: (Jonathan Rule 2018)

The initial experience uses the concept of open world gaming. This type of play uses a simple exploratory scenario where free exploration and no end goal take priority over linear and structured play. To take advantage of the capabilities of the virtual, the test scene allowed for interaction beyond simply viewing a digital recreation of the house. Through a series of identified moments in the building, hotspots were created to allow for students to pull out details of the building to reveal how the different elements come together as an assembly. These three-dimensional elements were also paired with detail drawings of that location to allow students to understand the relationship between the two-dimensional detail and the three-dimensional element.

The initial prototype was introduced to students alongside the lecture about the house. To test the weather the prototype scene helped students understand the content, the class was divided into two groups. One group was allowed to use the virtual reality scene and the other could only rely on what was learned during the lecture. Both groups were asked to answer a set of multiple-choice questions related to the house. The results showed that the group with access to the virtual reality experience performed better on the quiz than those that did not. In addition, the students who had access to the VR application were given a qualitative survey to ask them about their experience. This survey resulted in a very positive response when asked if they felt the VR application helped them gain a better understanding of the content that was presented in the lecture.

2.2. Virtual Reality Application Development

To further understand the effects of virtual reality on students learning process the project evolved into a more robust version of the experience through a series of in-depth modules related to the material content of the course. To achieve this the course partnered with the Center for Academic Innovation through the XR Initiative at the University of Michigan. The program was a pilot program that selected eight projects from different fields to advance multidisciplinary learning and teaching and create innovative learning experiences through extended realities. The resulting project for the construction course brought together game developers, architects, and experts in educational technology to develop the second iteration of the prototype which was titled, ‘Augmented Tectonics’.

The process for development built on what was learned in the prototyping phase but with adjustments made to support workflow between multiple groups as well as adapt critical insight from experts in educational technology. Unlike the previous model, the new application moved away from open ended play and chose to adapt a linear engagement of the content that integrated specific goals and segmented the learning experiences into finite modules. These modules were important in controlling the amount of time a student would be immersed in an environment which was recommended to not be more than 30 minutes.

2.3. Development Platform

The development of the application used Unreal Engine made by Epic Games. This decision came out of establishing a clear workflow between the application developers and the architects. While Unity is capable of similar workflows, Unreal at the time of development was better suited for the task. First, it facilitated the develop content using a familiar modeling software, Rhino 3D. This along with the Datasmith application provided by Unreal Engine, allows for a direct connection between the modeling software and the game engine. As models are built, they are directly linked to the established scene without the need for exporting and importing to take place. In addition, through the layer structure of the files, it becomes possible to directly set up collision with static meshes inside Rhino. Collisions are what make virtual space “tangible” by limiting a person’s ability to move through objects by giving them simulated physical properties. The second, advantage was the integration of Perforce’s Helix Core which allowed for version control. Version control allows multiple people to work on a single build while storing and tracking changes being made to all the digital assets, including source code and 3D models. As the project became more complex and with more people working on development it was important to have a common repository where changes being made were trackable and identifiable.

2.4. Development Phases

The development phases included: discovery, research, asset development, prototype review/testing and implementation. Each phase was to be carried out sequentially; however, unforeseen challenges related to the technology and limitations of its capabilities required the reassessment of objectives at various stages.

2.5. Discovery and Research

The discovery phase involved conducting a survey of what existed for virtual reality learning platforms, identifying best practices, and establishing connections to course content. This design research aided selecting an organizational framework of a gallery space for the curation of content. The gallery became a logical solution for various reasons. First, the scale of the space could be constrained to meet the immersive time requirements. Second, the series of rooms established a system that could be added on to for future expansion while simultaneously breaking up content into manageable chunks. Lastly, it did not rely on a singular precedent project which is limiting because of its specificity and inability to demonstrate the breadth of concepts and methods that one might encounter in construction.

This stage was followed by a research phase, which analyzed methods of curation for physical objects and digital objects. Careful consideration was given to understanding opportunities and limitation of displaying two-dimensional content and three-dimensional content. The translation of this material to a digital space is a challenge and limited by the ability of the technology to properly display polygons and pixels when rendering a smooth experience. This phase also considered possibilities for simulating illumination in the galleries based on real world examples.

2.6. Asset and Interaction Development

The development phase included the team of architects and application developers working in parallel on building assets as well as making those assets interactive. Taking what was learned in the first two stages the design team began to give shape to the galleries and their internal organization. To bring these containers into conversation with the content, each gallery was constructed using the material it was showcasing. The initial gallery that was developed was for the metals module which primarily focused on steel construction. Three spaces were configured as standalone pavilions that contained an introduction to metal processing, followed by details and cladding, with the last pavilion comparing two precedents buildings.

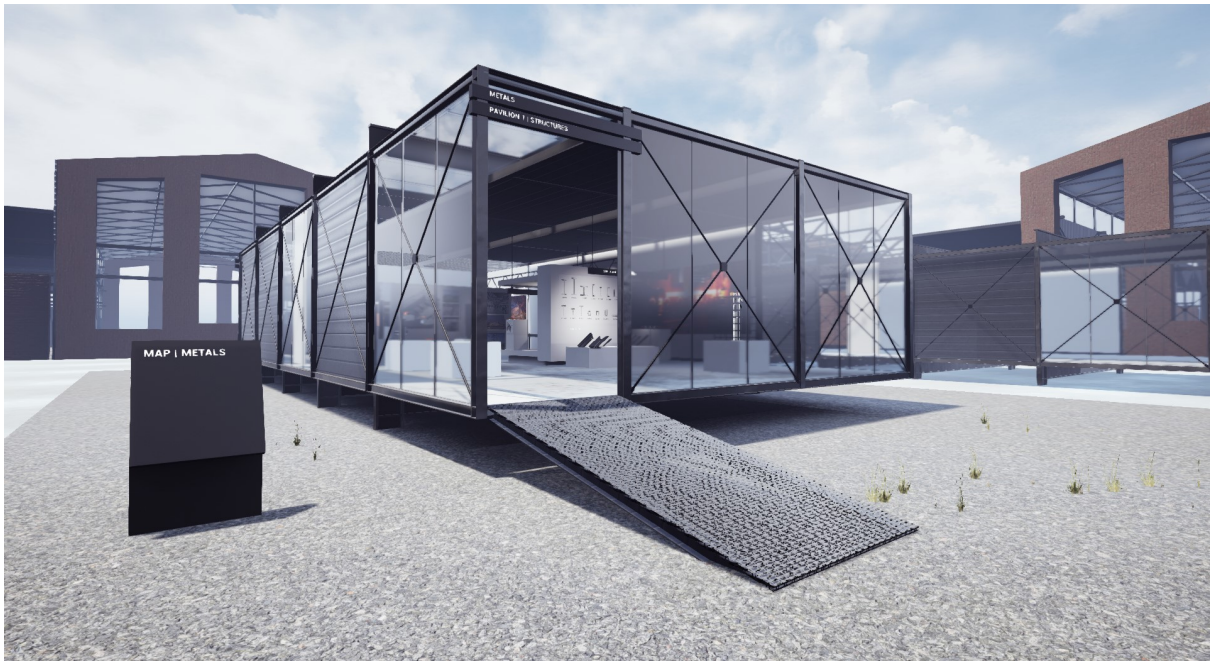


Figure 2: Version 1.0 Metals Gallery. Source: (Jonathan Rule 2019)

As content was created for the pavilion, the application development team was tasked with adding interactivity to the various assets in the virtual world. To turn the models from static objects to dynamic pieces required in-depth storyboarding to communicate the intention behind the interactive visualization. These interactions had a range of complexity, from a simple button press to trigger an animation, to more complex interactions that would require students to assemble structures and size steel members. It was also important to introduce a recordable metric to be able to assess the student's ability to understand the presented information. This took the form of questions at the exit threshold of each gallery and a matching challenge at the end of the module. To move between galleries, students first must answer a series of questions or participate in a scavenger hunt based on the content they just reviewed. Once they answer the question correctly the next space is unlocked, and they can proceed.

To end the module students are presented with a matching challenge. This challenge combines a randomized set of details related to the module, drawn as two-dimensional drawings as well as their three-dimensional representation. The challenge requires students to correctly associate the model with its respective drawing.

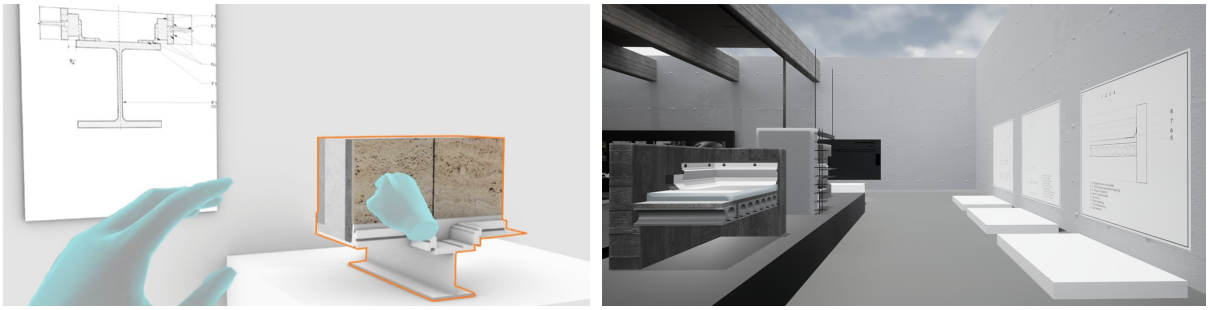


Figure 3: Matching Challenge. Source: (Jonathan Rule 2019)

To record the progress of an individual, the application was linked to a live google spreadsheet. The spreadsheet would record completion of the different thresholds, and matching challenges as well as record a timestamp and platform used, VR or desktop.

2.7. Playtesting

Before fully implementing the application into the course, it was crucial to review and test the initial module. While the development team understood the design and user interface very well, it cannot be assumed that someone using the application for the first time would have the same experience. To facilitate this phase of inquiry, the team turned to VR playtesting and specifically the Meta Playtesting guide. This process employed ten student testers and involved a series of questions that were asked while they were immersed in the application and afterwards. According to Schell Games, “the goal of playtest questions is to get unadulterated feelings from the person. You do not want to lead them in any way, but you want to find out what they thought.” (Schell Games, n.d.) For example, during immersion subjects are asked to describe what they are doing at specific moments. This helps the development team assess whether the scene or interaction is being used in the intended manner.



Figure 4: Playtesting analysis with students. Source: (Jonathan Rule 2020)

The post-play interview, included questions like; was there anything you wanted to do that you couldn’t? This helped the team to gauge elements that might have been overlooked. After playtesting, the team synthesized and prioritized areas of improvement based on the responses. Some of these improvements included the following. Limited access to a headset, or motion sickness resulting from the use of a headset, necessitated that the app also include a desktop version, free of virtual reality. The desktop version could be navigated via a computer screen using keyboard controls and a mouse. While this version did not allow for an immersive experience it was important to make available as to not exclude anyone from accessing the content. A second improvement included developing a clear method of way finding. During playtesting it was observed that students were not sure where to go next. The metals module allowed for students to leave the pavilions and roam which caused confusion. This was resolved by restricting movement to the interior of the galleries and ganging them together to create a linear sequence between content. This also established a clear start, finish, and separation between groupings of content where threshold questions or challenges could be placed and found easily. Each module would now start with an overall description of the content and a level map as a visual guide. Within the gallery spaces, way finding was emphasized through arrows and a sequential numbering of an audio guide. While audio was provided, students also mentioned that it would be beneficial to have sub-titles or text for the audio since some learn better through reading.



Figure 5: Module map and quiz threshold. Source: (Jonathan Rule 2024)

Lastly, the start menu was redesigned to restrict free roaming and allow for direct access to the different modules. This space integrated a training module that would introduce students to the navigation system and the nuances of interacting with the content. These adaptations were made to the current metals module and added directly to the subsequent modules for wood, concrete, and masonry construction.



Figure 6: Concrete module: foundations, columns, and slabs. Source: (Jonathan Rule 2024)

3.0 RESULTS

3.1. Post XR Surveys

The application Augmented Tectonics was fully implemented into the construction course from 2021 – 2023, covering four material modules: metals, masonry, concrete, and wood. During the semester students attended the lecture for each of these materials and were given two weeks to complete the respective module. At the end of each semester students are asked to take a survey to assess the use and acceptance of the application in the teaching and learning process. Over the three years there has been a response yield between 122 students (2021) and 78 students (2023). Below are the results of a selection of qualitative questions compared over the years in addition to select student responses.

3.2. Knowledge Building

Students were asked to evaluate on a scale of 1 – 10 with 1 being low and 10 being high, how they felt the Augmented Tectonics platform aided in gaining knowledge about the content of the course. The results indicate that this has mostly been a positive method for learning with most students reporting between a 7 and 10 and comments including, “Awesome use of technology and great educational aid to visual learning.”

3.3. Enhancing Understanding of Lecture Content

The next question asked students to respond to the applications ability to help them better understand the content that was presented in the lectures. These responses hoped to illustrate that it had a positive impact of resolving unanswered questions a student might have regarding content. Like the previous question students primarily found this supplemental support favorable with many responses between 7 and 10 and comments including, “I feel like this was a good way to show us what we were learning in class without having to use actual physical versions.”

3.4. Understanding 2D to 3D Translation

This question asked if the experience helped the student further understand 2D drawings of 3D objects as they relate construction and construction details. Once again, the results support the claim that the application was a helpful resource, with feedback including, “I like that I was able to see how materials were connected to one another more closely. The 3D view made it a lot easier to understand.”

3.5. Improved Visualization

Building on the applications ability to help understand three-dimensional content, the next question asked if the experience helped improve the visualization of complex assemblies and details. As with the previous questions most students scored this positively between 7 and 10, with comments including, “I thought it's a great idea to do these VR quiz/videos. I learned a lot more because the different building layer were very clear visually.”

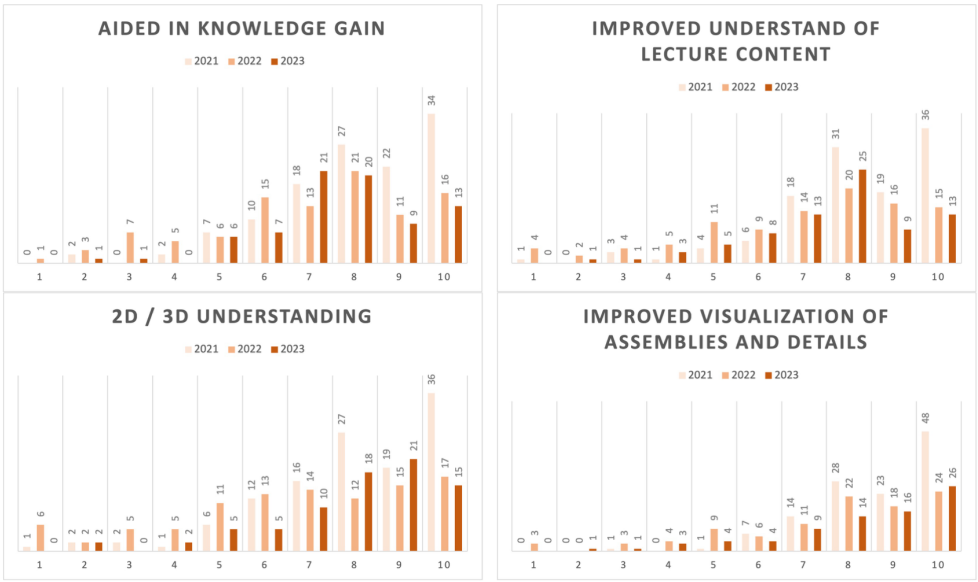


Figure 5: Recorded student response data 3.2, 3.3, 3.4, 3.5. Source: (Jonathan Rule 2024)

3.6. Course Metrics Platform

During the course two types of content review methods were administered. The first was the threshold questions and challenges built into the application. The second was a multiple-choice quiz using google forms. When asked which content review method was preferred, students highly valued the in-application method with an average of 83% approval over the three years. When asked why, some students answered that they felt the thresholds and challenges were directly applicable to what they were learning about. The multiple-choice quizzes required rote memorization of content that might or might not be meaningful. Many of the students that preferred the multi-choice method did so due to legibility issues and motion sickness that occurred while going through the desktop or virtual reality version.

3.7. User Interface Platform

All students were required to use the application in virtual reality at least once. Virtual reality can be complicated for first time users to set up and in this case required an in-class tutorial to show students how to connect the head mounted displays to the computer and application. As part of the introduction tutorial to get students acclimated to the technology, each student completed the in-app tutorial as well as the first assigned module using virtual reality. Afterwards, students had the option to choose how to engage with the application. The students were given access to three labs on campus. Two of which were equipped with virtual reality headsets and one with the desktop system. When asked which platform they used, the survey revealed (Table 1) that over the years, most students chose to use the desktop option over a more immersive virtual reality experience.

Table 1: UX Platform Preference Source: (Jonathan Rule 2024)

	2021	2022	2023
Virtual Reality	40.20%	3%	7.70%
Desktop	45.90%	88%	74.40%
Both	13.90%	9%	17.90%

3.8. Interpreting the Results

These qualitative responses were helpful in beginning to understand the value of creating an experience like this for learning. While the results reveal a limited use of virtual reality by students it is also important to understand that the data does not present this medium as a failure. More robust studies have been conducted on the effects individuals being repeatedly exposed to the technology. According to Eugy Han:

> Inferences based on single session exposures or obtained through analysis of just a few sessions when participants are adjusting to the novelty of a medium are plagued with technical difficulties and can be misleading or incomplete." (Han 2022)

First time users are usually apprehensive about setting up the headsets and how it is used. The unfamiliarity results in many users quickly abandoning the technology for something that is quicker to access and more familiar. In addition, this platform does not account for the benefits that group interaction can have within these immersive worlds. Studies by Khojashteh and Stevenson-Won reveal that participants in group situations become more comfortable with the medium and through collaboration learn its affordances. (Khojashteh and Won 2021)

CONCLUSION

This use study tests the potential extended realities poses in a teaching and learning environment for a specific scenario of architecture construction. Beyond this example, these tools also hold opportunities for communication between remote or collocated individuals immersed in multisensory spatial experiences. But for now, the use of these despatialized visualization technologies has seemingly generated more of a ripple than a wave when compared to other technologies adapted by architecture and as illustrated in the diagram "Prevalence of computation in Architectural Design." (Garcia et al. 2023) This can be attributed to several reasons but primarily is a question of access. Virtual reality, for one, is still expensive and has not fully been adapted by the public. However, even in a scenario where the technology is available, the process for a new user to navigate setting up the hardware and feeling comfortable using the new tool is a complicated process. Most first-time users, as mentioned before, become apprehensive at this stage and prefer a quicker and more familiar platform. This is not to say that virtual reality will not become more user friendly over time, but for now it is a hurdle that impedes a more widespread use. Despite these limitations, XR's latent potential and reflecting on the history of technology in architecture, one can only ask, will extended realities remain as a ripple or is it an undetected tsunami? The example studied here remains inconclusive in answering this question, but it does, returning to Carpo's statement, offer an example to reflect on what we could not do without XR based immersive virtual learning environments in the classroom and hint at the possibilities that they hold for the future of architectural education.

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A New Way of Presenting: Redefining Architecture and Design Exhibition through Virtual Realms

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ABSTRACT: This research offers a thorough examination of the online exhibition organized by Bahçeşehir University, highlighting its methodology and development within the framework of architecture and design department. The exhibitios were a reaction to the COVID-19 pandemic's problems and marks a major move away from conventional physical exhibits and toward virtual formats. This paper's main goal is to investigate how the institution used digital technology to showcase student work in an immersive, interactive setting. In order to successfully display student work, the virtual exhibition made use of a variety of digital tools and platforms, such as 3D modeling, and interactive web-based apps. The study looks at how the virtual environment was designed and implemented, emphasizing how it promoted accessibility, engagement, and interaction for a worldwide audience. The study also places the university's virtual exhibition in the larger context of educational exhibitions' digital development. It offers a thorough overview of the state of digital exhibition practices in architecture and design education today by drawing similarities with the methods used by other institutions. This research adds to the increasing conversation about the future of academic exhibits by speculating that, in the digital era, virtual exhibitions may serve as a good substitute for or addition to physical exhibitions, in addition to serving as a temporary fix during times of crisis. In order to help educators, students, and exhibition planners in the domains of architecture and design navigate the changing requirements of exhibiting creative work in a world that is becoming more and more digital, the research intends to offer insightful information.

KEYWORDS: exhibition, virtual exhibition, architecture, design

INTRODUCTION

Humans have an innate propensity to exhibit their creations to others and display them in accordance with their individual preferences. This circumstance can be traced back several centuries. Even caveman art depicts the transmission of knowledge to future generations, and their sharing of personal experiences. As a result, individuals have always been on the lookout for a suitable place for presenting. Due to this requirement, museums and exhibition halls have acquired prominence. This study explores the contemporary trend toward virtual exhibits, which was made possible by the COVID-19 pandemic's extraordinary obstacles and supported by the quick development of digital technology.

The turn of the twenty-first century brought about a paradigm shift in people’s understanding of and interactions with exhibition venues. Integration of technology and design has taken on a greater significance in this modern era. As a result of technological advancements, exhibition spaces are moving into the virtual world. Due to the difficulties in accessing tangible exhibition spaces with covid-19, virtual exhibition spaces have grown in significance. During this time, many of the world's most famous museums used virtual environments.

Universities are also subject to a comparable circumstance. At the end of the semester, many universities have decided to conduct their exhibitions in digital environments. The shift to virtual exhibitions has been especially noteworthy in disciplines like architecture and design, where visual representation is fundamental to creative expression. In order to display student works, universities and other educational institutions have adopted digital platforms as a means of addressing the issues presented by the pandemic. This method not only provided consistency in the face of difficulty but also expanded the possibilities for teaching and display techniques. The shift to virtual exhibits has presented opportunities as well as challenges, leading to a reassessment of conventional exhibitions and audience engagement paradigms. Virtual spaces provide a cutting-edge platform that cuts through geographical barriers to reach a wider and more inclusive audience. This change is a proactive strategy that reimagines the relationship between the exhibit and the audience.

This paper explores the development of virtual exhibition spaces, concentrating on the exhibition held by the host university’s department of architecture and design between the 2020–2022 academic years. This time frame is important because it represents the convergence of past years' experiences and input, resulting in a more polished and functional virtual exhibition setting. The process of moving from physical to digital media will be examined in this study, with a focus on the collaborative efforts of academics and students.

The study seeks to provide light on the creative application of digital technologies like SketchUp, Enscape, and iStaging by closely examining the virtual exhibition's concept, development, and execution stages. The initial selection and modification of student designs, the modeling of virtual worlds, the incorporation of interactive components, and the overall effect on viewer engagement will all be covered by the structured study. The paper

will also go over the wider ramifications of this digital revolution for exhibitions in educational settings going forward, especially in the fields of architecture and design. It aims to shed light on the possibilities of virtual platforms as a viable—and maybe even better—than-temporary replacement for conventional exhibiting techniques. In light of the constantly changing landscape of architecture and design education, the research emphasizes the value of adaptation, creativity, and perseverance in the face of adversity.

1.0 THE EVOLUTION OF EXHIBITION SPACES

1.1. Historical perspective of exhibition spaces

Exhibition spaces are more than just physical venues; they are representations of cultural histories and intellectual developments. Due to their evolution as spatial entities and the effect of different architectural, social, and political settings, they have become important venues for exhibiting art and artifacts (Simonsson 2014). They have changed over time, reflecting a wide range of cultural, technical, and educational developments. This evolution captures not just the evolving aesthetics of architecture and design, but also the changes in society about people's perceptions of and interactions with art, history, and knowledge. A growing democratization and accessibility of information has characterised the history of exhibition venues, from the private collections of the Renaissance to the public museums of the Enlightenment. The *cabinets of curiosities* of the Renaissance were the earliest kind of private collections, emphasizing the individual's quest for knowledge and curiosity with the natural and creative worlds (Findlen 1994). These private collections, which combined the intellectual and the eclectic, were the forerunners of contemporary museums. A paradigm change was brought about by the Enlightenment, which emphasized the value of public access to information and culture. Public museums began to appear during this time, such the British Museum, which opened its doors in 1753. These establishments sought to benefit the general people as well as the elite, democratizing access to information and the arts. This progression tells the tale of how exhibition spaces went from being exclusive cultural strongholds to becoming open-access hubs for interaction and teaching (Bennett 1995).

1.2. The role of exhibitions in architecture and design

Exhibitions have a critical role in forming students' professional growth and the instructional approach in architectural and design education. Physical exhibitions have long been a mainstay of educational settings, giving students a concrete venue to present their models, sketches, and design concepts. According to Salama and Wilkinson (2007), these exhibits are more than just showcase events; they are essential to the educational process since they encourage public participation, peer review, and critique. Exhibitions provide students a chance to network with industry experts, prospective employers, and the academic community. They provide as a platform for networking where students may exchange ideas, get feedback, and establish relationships that could result in future employment prospects.

1.3. Transition from physical to virtual exhibitions

The introduction of digital technology in the twenty-first century has the potential to completely change the idea of exhibition venues. The COVID-19 epidemic has expedited the transition to virtual exhibits, which signifies a fundamental transformation in the curation and experience of art and cultural objects in addition to a technological adjustment.

Virtual settings may not entirely duplicate the distinct sensory experience that physical displays give. The knowledge of architectural and design concepts is greatly enhanced by the tactile quality of materials, the scale of models, and the spatial connections in physical presentations (Pallasmaa 2012). But the advent of digital technology has made it possible to combine conventional techniques with virtual exhibits. The teaching toolset has been enlarged by this dual approach, enabling more creativity and flexibility in presenting techniques (Oxman 2008). Virtual exhibits have the potential to transcend both physical and geographic boundaries, providing increased accessibility and facilitating interaction between student work and a worldwide audience (Jabi 2013).

It has been observed that virtual exhibitions may eventually take the place of actual ones depending on how quickly technology advances. Since there are now virtual exhibition spaces, the locations are no longer as significant. Technology bridges cultural divides and shortens distances. According to Dumitrestu et al. (2014), virtual exhibits are said to include attributes including accessibility, relevance, localization, and interaction. It is crucial to follow these guidelines and not omit them while creating virtual exhibits. The same study suggests that virtual exhibitions might be designed or altered faster than real ones. This was viewed as a favorable aspect as well. Furthermore, virtual exhibits are said to have many benefits over physical ones by Ciruera et al. (2016). These are the convenience of repurposing the space, the lower costs, and the fact that the things on exhibit pose no security concern. Considering these advantages, one of the long-standing debates is whether virtual exhibits can take the place of real ones. Lester (2006) conducted a research to investigate the possibility of this debate. The author contended that because the exhibition is a sort of communication in and of itself, it interacts with visitors in an indirect manner. In this sense, neither can be replaced, but their positive and negative qualities mutually reinforce one another. Lester noted in the same study that a virtual exhibition cannot be real in the strictest sense of the word, but he also mentioned that the visitor has much more flexibility in the virtual world.

Universities have been using virtual exhibitions more and more in the past several years to display student work, especially in disciplines like architecture, design, and art. A lot of colleges' architecture departments were used virtual exhibitions to showcase student work, especially considering recent restrictions like the COVID-19 epidemic.

In a study conducted on virtual exhibitions held in design faculties of universities, a total of 50 virtual exhibition examples were examined (Çalışkan 2023). According to this study, 33 virtual exhibition samples were developed on one single website. The most prevalent method in these instances was to display student names and project images. The student project may be seen with one click. Additionally, tools like *Anyflip* are used to display items like catalogs or magazines. This software allows page switching. Two institutions uploaded exhibition films on *YouTube*. It was fascinating that *Instagram* was used for the virtual display in addition to Youtube. Again, intermediary tools like *Artsteps* and *Hubs Mozilla* that provide templates and virtual exhibitions are used. Many institutions use Artsteps, a web-based program that lets users design three-dimensional spaces/exhibitions with an intuitive interface. This program supports three-dimensional models and two-dimensional pictures and videos. This creates a more sociable platform. In addition to building their own designs, users may use templates. These programs simplify and speed up model preparation. For their virtual presentations, fifteen institutions produced 3D models. Daekin University, one of them, made the exhibit by 3D scanning real studios and transferring the images to a computer environment. Yaşar University used the same method to exhibit student projects.



Figure 1: Different ways of applying Virtual Exhibitions. (1-Yaşar, 2-Tulane, 3-Marmara,4- Antalya Bilim) Source: (Yaşar University 2023, The Architect's Newspaper 2021, Marun Mimarlık 2023, Antalya Bilim University 2023)

Others have used exhibitions that are fully computerized. Three of them, the University of Nocias, Tulane School of Architecture, and Istanbul Technical University, replicated their actual spaces. Others took advantage of the pre-built locations that were linked to their application (figure 1). Bahcesehir University's exhibition was the only exhibition under review to have its display created in a fully made-up virtual environment. It might be argued that this particular circumstance is significant for drawing viewers' attention and setting it apart from other examples.

2.0 THE VIRTUAL EXHIBITION EXPERIENCE

2.1. The motivation for the virtual exhibition

Sharing the results produced in courses or extracurricular activities is one of the most motivating aspects of architectural education for students. It ensures that their work is disseminated to a broader audience and be appreciated by people. According to Toloudi (2016), exhibiion brings the students towards the public through a celebratory process, by inspiring and supporing them with confidence. It also provides the chance for them to inspect each other's work and conduct comparisons, leading to informal competitions which are also motivational for students of architecture (Ilkovičová & Ilkovič 2018).

Before the pandemic struck the whole world with its undeniable effects on all aspects of life, student work exhibitions were conducted conventionally in physical environments with printed material. However, in 2020, during the lockdown due to Covid-19 pandemic, many things including the methods of architectural education were changed. Architectural courses, as well as extracurricular activities were transferred to online and virtual environments. This led architectural education institutions to search for new methods for sharing the products of the activities conducted during the academic semesters (Ceylan et al. 2020). With this aim, Bahcesehir University Faculty of Architecture and Design generated a new way of exhibiting student work through a virtual exhibition, which throughout several years evolved to a comprehensive presentation of faculty and university activities.

2.2. The evolution of the virtual exhibition

The idea of sharing student work on online platforms firstly led to social media applications. Participating students were encouraged to share their work on Pinterest, which then led to a collaborative board on the platform. Additionally, faculty Instagram account was started to be used more effectively and frequently to present student work during and at the end of the semester. However, that was not enough to satisfy either the students or the faculty regarding the dissemination and inclusiveness of the exhibitions. At that point, the idea of a comprehensive virtual exhibition emerged and methods for creating the exhibition started to be investigated. In the beginning, the

idea was simple: To design an exhibition space for each academic year's design studios and populate it with selected student work. The initial layout for the exhibition space consisted of a lobby in the middle and 4 connected exhibition rooms reserved for each academic year's design studio (figure 2). The overall place was modelled in Sketchup by the coordinators of the exhibition, and each exhibition room was designed by the research assistant assigned to that studio. When all the student work was added to the exhibition rooms and all rooms were assembled in a single model, the virtual exhibition for 2019-2020 Bahcesehir University Faculty of Architecture and Design Spring Semester Design Studio became ready for visitors. Actually, there were multiple exhibitions because each department in the faculty; architecture, interior architecture and environmental design, and industrial design departments, had their own models and independent exhibitions. Thanks to Enscape (https://enscape3d.com/), a software being used as a plugin on Sketchup and several other 3d modelling software, it was possible to generate an executable file that can operate standalone on any PC. Moreover, the executable file made it also allowed an immersive VR experience through a suitable VR headset. Thus, the link to the executable file was shared on social media and the faculty website, so that anyone could download it to interactively experience the virtual exhibition. Following the publication of the executable file, within the designers' team it was argued that it would have been better if the exhibition could also be visited using mobile devices. That could ensure the virtual exhibition to be disseminated to a much broader audience. Therefore, a third application was used: Cloudpano, a website for generating 360 degrees virtual tours. 360-degree panoramic images were rendered on Enscape and uploaded to the virtual tour on Cloudpano. After a few quick adjustments on Cloudpano for adding tags and assorting the images, the virtual tour became ready to be visited via any device including mobile phones (https://app.cloudpano.com/tours/JQoO76Xw2).



Figure 2: 2019-2020 Academic Year Virtual Exhibition. Source: (Authors 2024)

As a result of the positive feedback received from visitors, participating students, faculty members, and the university administration, it was decided to repeat the virtual exhibition for 2020-2021 Academic Year, this time with a broader scope. It was aimed in that year's virtual exhibition, in addition to design studio outcomes, selected student work from other courses, extracurricular activities, and faculty announcements were presented in the exhibition. These additions did not change the workflow too much, but they affected the required effort to be put on the design and modelling processes. The design team came up with a new layout which was linear, consisting of two corridors connected to each other in the middle with the lobby (figure 3). The lobby included a welcoming area, starting point of the tour, as well as overall information about the faculty and connected units. A mezzanine floor was added on top of the lobby for exhibiting extracurricular activities conducted in the faculty such as workshops, seminars, and conferences. Two corridors connected to the lobby contained student work from design studios and other courses, one for the Fall and the other for the Spring semester. The exhibition coordinators decided which course would be exhibited in which space, but the design of each space was carried out by the assigned teaching assistant of the relevant course. Additionally, it was also aimed that year's virtual exhibition was more interactive and dynamic. Therefore, a careful investigation was conducted on websites and software providing virtual tours. As the result of the investigation, a website called iStaging was selected as the most effective and feasible option (www.istaging.com/en). iStaging had its own built-in application that allows adding images, tags, videos, and embedding external websites. Even though these operations were quite time consuming in the post-production phases, the resulting tour had been much more dynamic and therefore interesting for the visitors (https://livetour.istaging.com/dbe6941e-b03d-41ac-bfd4-9099f028c220?_ga=2.39688609.309255714.1625561957-1238256088.1625561957&index=1).



Figure 3: 2020-2021 Academic Year Virtual Exhibition. Source: (Authors 2024)

In its third year in 2022, the virtual exhibition became a tool for presenting the faculty and its departments, as well as the administrative units that collaborate with them. The layout changed once again, allowing a continuous circulation that gets back to the starting point after the tour is over. This layout also allowed more efficient interior-exterior relationships in addition to a courtyard that was also utilized as part of the exhibition (figure 4). The software and applications used for the virtual exhibition remained the same. There were no major changes in the workflow, but only minor adjustments and improvements caused by the increase in the amount of provided information. Additionally, as the 360-degree virtual tour platform iStaging offered new and improved features, it was possible to add new elements to the virtual tour such as teleport between different tours and more advanced tags for items (https://livetour.istaging.com/4bda49f9-a32e-4de6-9ab7-95d8f98826cc?index=1).

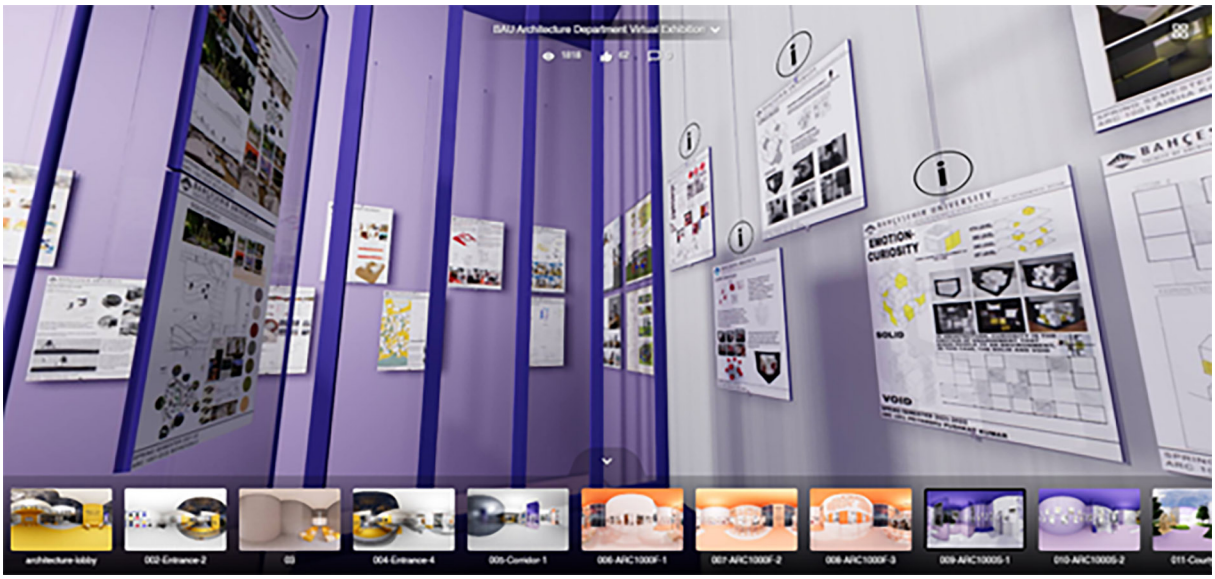


Figure 4: 2021-2022 Academic Year Virtual Exhibition. Source: (Authors 2024)

2.3. Workflow of the virtual exhibition

Composing the virtual exhibition each year from scratch requires a lot of work by various stakeholders such as students, research assistants, studio coordinators, and the core design team. Moreover, it requires strong collaboration and efficient use of time. Preparations for the virtual exhibitions need to start at the beginning of the spring semester to be ready for the summer period. In the light of the experience gained from three years of virtual exhibition, the workflow consists of 7 sequential and/or simultaneous steps that are executed by different stakeholders: *selecting and collecting student work, designing and modelling the common exhibition space, designing individual rooms/spaces for each studio/course, gathering all exhibition spaces in a single model file, completing fine adjustments and rendering 360 panorama views on Enscape, transferring rendered images, adding multimedia, tags, and external links to the tour on iStaging,* and *testing the virtual exhibition in VR and mobile devices for publishing and announcing the virtual exhibition on faculty website and social media platforms*. Executing these steps in a successful way ends up with a thriving virtual exhibition.

Selecting and collecting the student work for the virtual exhibition is performed at the end of each semester, after the final exams or submissions are completed. The assigned research assistant for each course defines a template

relevant to the virtual exhibition and shares it with the owners of the selected work. Students adapt their final work to the given template and submit the posters to the research assistant, if available they can also submit a 3d model of their work. Additionally, students are asked to fill in a consent statement form for their work to be included in the virtual exhibition and published online as open source.

The core design team gathers to discuss and define the general concept and form of that year's virtual exhibition. After the decision is made for the overall layout and locations for each studio and course are decided, the template of the exhibition space is modelled on Sketchup and shared with all research assistants to add the designated exhibition rooms for the studios or other courses they are responsible for. The core design team is also responsible for the design and modelling of the lobby which includes a welcoming space in addition to the exhibition of extracurricular activities, faculty news, and university units that are important for the architecture and design students. As the lobby holds important common information about the faculty, it is the same for each department's exhibition with minor differences such as colours or furniture.

Each studio and course included in the virtual exhibition is located in a separate room or space. Therefore, each of them needs to be designed by the instructors and research assistants of that particular course. That process is different in each course, whether to be designed by the instructor itself, or by the research assistant of the course. After the design and modelling of the space is completed and relevant student work is added, the Sketchup file is shared with the core design team to be added to the main model file.

After the core design team has received all model files of separate exhibition spaces for design studios and other courses, they put them back into the template file they shared with everyone in the beginning. At this point, they deal with problems like loss of texture, overlapping surfaces, and points that don't match with each other due to version differences or scale issues. After the problems are fixed and final controls are done, the virtual exhibition is ready for further steps on other software.

Next step of the virtual exhibition is executed on Enscape, a plugin for real-time rendering running on Sketchup and other 3d modelling software. This process is covered by the core design team, adding lighting, furniture, andother amenities to the model, walking through the model to check potential mistakes, and testing the exhibition on immersive VR using headsets. After the checks are complete, 360-degree images are rendered from each necessary space for design studios and other courses to constitute the VR exhibition for mobile devices.

All 360-degree panorama images are transferred to iStaging, a web-based platform for virtual tours. The images are assorted in a reasonable way regarding the circulation in the space. As soon as the assortment is completed, it is time to work on each image separately to add multimedia, tags, and external links where necessary. The core design team is responsible for the images from the lobby and common spaces for faculty activities, as the exhibition spaces of the studios and other courses are dealt with by the designated research assistants.

Following the final checks on the virtual tour on iStaging regarding the functionality of the tags, links, and multimedia, and trial runs on the tour, the virtual exhibition is made public and the links for each department's exhibition is shared online on faculty website and social media accounts. Thus, through a single link, anyone on anywhere on earth is able to visit the virtual exhibition for Bahcesehir University Faculty of Architecture and Design. The second option for the virtual exhibition is the executable file generated on Enscape. It is also uploaded to the faculty website and announced on social media. It is accessible for anyone on a PC, allowing real time walkthrough in the virtual space for exhibition.

3.0 DISCUSSION AND CONCLUSION

3.1. Outcomes

The long and hardworking process of the virtual exhibition pays off in several ways. First of all, it has a significant contribution to the dissemination of the academic year outcomes. In cases where the outcomes are exhibited in physical environments, the visitors are limited to the people that are directly related to the faculty; instructors, students, and the people they personally invite. This situation makes the physical exhibition less effective for reaching a large audience. On the other hand, the exhibition conducted on social media can reach relatively larger audience thanks to the number of followers of the faculty account and related accounts, but the screening time for the social media exhibition is limited to several seconds only. Therefore, it is not effective as expected. The virtual exhibition as explained in the scope of this paper reaches a relatively large number of audience. Table 1 shows the viewing numbers of the virtual exhibitions each year from 2020 to 2022, based on the departments of faculty of architecture and design. The table shows that in 3 years, the virtual exhibition has been visited more than ten thousand times. In addition to the viewing numbers, virtual exhibition also provides a more effective experience, dragging people in with its immersive design, mimicking the attributes of a physical exhibition.

Table 1: Viewing numbers of each virtual exhibition. Source: (Authors 2024)

Year \ # of visits	Architecture	Interior architecture	Industrial design	Total
2020	1710	803	1272	3785
2021	1784	786	758	3337
2022	1817	767	714	3298
Total	5311	2356	2744	10420

Second important contribution of the virtual exhibition is that motivates students to be better at their courses so that they can be a part of the exhibition. Unstructured talks with students from different departments revealed that they care about the virtual exhibition and having their work showcased in its scope. It is on one hand an informal competition between students that leads them to be better in the future, and on the other hand it is prestigious for them to show their work to people outside the faculty such as relatives and friends in such an immersive and futuristic digital environment.

Last but not least, the process of preparing the virtual exhibition contributes significantly to the teamwork capacity of the faculty. As stated in the scope of this paper, preparing the virtual exhibition requires strong collaboration and dedicated teamwork. Even though it is not always easy and requires sacrifice for the faculty members to reserve time for this extracurricular activity in addition to all the existing workload, it is good to get out of the regular work, be a part of something successful that adds a value to the identity of the faculty itself and be appreciated by the people from within and outside the faculty.

CONCLUSION

The case of virtual exhibition at Bahcesehir University Faculty of Architecture and Design exemplifies how a virtual exhibition as a new way of communication can contribute to the educational and academic environment regarding various aspects. The process and workflow explained in the scope of this paper can be a sample for virtual exhibitions in the future, forming a useful model. However, requirements and opportunities based on the location, time and subject may affect the virtual exhibition to alter in the future. Especially, becoming more interactive, dynamic and appealing to the user must be considered to be aims of virtual exhibitions. Therefore, using alternative and more advanced software like Twinmotion, Blender, and game engines such as Unreal and Unity must be studied to come up with more effective and successful virtual exhibitions in the future.

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The Role of Playgrounds in Children's Cultural Worlds. Are Playgrounds Redundant in the Urban Environment?

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ABSTRACT: As we struggle with the demands of rapidly growing cities, the needs of our youngest citizens are being ignored. Due to how space is allocated in cities today, playground space has decreased. The loss of playground space denies children their right to play freely. This paper argues for a reconceptualisation of play space and for cross-disciplinary collaboration to get us there. Documentation of playgrounds from Europe and the US was used to outline the changes in playground design since the start of the 20th century. The concept of free play was assessed by reviewing literature and theories of diverse disciplines such as sociology, education, and cognitive developmental psychology to understand its role in children's cultural world and well-being. The philosophical works of Foucault, Hobbes, and Rousseau were included to define the notion of childhood in the reflection of the values of different times. Building regulations from North Rhine-Westphalia, Germany were considered to understand legal planning requirements for playgrounds and their relevance for urban space allocation. The findings show that playground design has been diverse over time while its purpose remained unchanged. Unsupervised outdoor play is an essential element that creates children's culture and alters culture as such. Apart from having health consequences and impacting their cultural capital, the lack of contact with nature-related playground space has a detrimental impact on children's social development and deprives them of agency. The paper concludes that changes in procedures for authorities and architectural education are necessary to generate improvements. A cross-disciplinary collaborative approach is suggested to understand children's needs and devise solutions addressing the challenges in architecture and planning.

KEYWORDS: outdoor play, playgrounds, urban childhood, architectural education, child development

INTRODUCTION

Working as an architect and urban designer in North Rhine-Westphalia, Germany, I often asked myself whether the planning and integration of playgrounds into urban design schemes is truly done in the best interest of children. It was only when completing an MA in Childhood Studies a few years ago, that I finally understood that the way we approach children's rights in urban planning is inappropriate and hazardous to children's health and culture. Research indicates that accessible space for children in cities is crucial to their social, physical, and intellectual development through play and exploration (Gebauer and Hüther 2003). Although decisions about urban planning impact children's lives, their participation and opinions are not comprehensively included in urban planning processes. Playground space is vital as an urban space exclusively reserved for children to play freely. This space is shop and advertising-free. Children can room independently and be noisy, behaviours that are usually forbidden in other spaces where adults tend to interfere in children's play (Baumann and Wolf 2016). The benefits of playgrounds are wide-ranging. The equipment is mainly gender-neutral and designed to stimulate children's interest in physical exercise. Playgrounds can be a meeting point for different social classes and can also lead to playing in mixed-age groups. This facilitates peer learning opportunities, helping younger and older children take on different responsibilities and engage in different types of problem-solving (Hüther 2008; Vygotsky 1978). As a result, playmates and playgroups can change flexibly.

However, research over the last two decades has shown that outdoor play is under threat. In 2005, Karsten found that children in Western countries play outside less than ever before and have less contact with nature than previous generations. Kernan (2010) attributed this phenomenon to the changing urban environment where children's outdoor experiences are restricted to space provided in schools, daycare, or the home. It could be that children are no longer interested in playgrounds as suggested by Brussoni et al. (2012) who found that play space and equipment were failing to meet children's interests. If we consider free play in nature, we find barriers to outdoor play coming from concerns about safety, such as traffic, "stranger danger" and the lack of natural places within reach (Sandberg 2012, 185). In 2016, researchers found that 70 % of UK children under 16 visited the natural environment only once a week, while 12% never visited (Hunt et al.). Reduced contact with flora and fauna harms mental and physical health and damages our essential relationship to nature (Soga and Gaston 2016; Giusti et al. 2018), a relationship that is needed to understand the environment as a vital resource, and ultimately to be able to protect it against destruction.

The conference theme "Architecture into the Unknown" highlights concerns about future paths, and uncertainties around social and spatial resources, and climate change conditions. Urgent answers are needed to avert health and cultural losses that will cause lasting damage to children, society, and us. Research can provide resources to

help us shift towards urban design that allows children to play freely outside, but so far, we have been unable to implement fair and healthy urban planning grounded on this basis. This means that, as architects and urban planners, we are neglecting children's needs and rights. The reluctance to prioritise children's needs may stem from a lack of awareness of disciplines like Childhood Studies or Health Promotion in architectural education.

Having learned from these disciplines, I now understand the impact planning decisions and design can have over the human lifespan, and this knowledge significantly changed my professional approach. I believe that it is necessary to collaborate with experts outside architecture before, during, and after the completion of projects. Evidence from different disciplines can help us shape priorities in planning strategies and decisions to improve the quality of space, enabling us to create a healthy and just built environment. This paper focuses on unsupervised outdoor play in urban settings in Western Europe and the US to demonstrate the role of playgrounds in children's play, culture, and well-being.

1.0 URBAN PLAYGROUNDS IN WESTERN EUROPE AND THE US

1.1 Development of urban playgrounds

The development of the playground over the last 150 years shows striking attitude shifts. In the early 20th century, when child labour ended and children were left by themselves while parents worked, social reformers invented the playground as an urban space focused on safety, physical exercise, preventing criminality and protecting children from danger. Playgrounds were fenced in, equipped with gymnastic apparatus like swings, climbing frames and slides, were supervised, and often divided by gender. The concept of the playground can be traced back to Thomas Hobbes' 1651 book, Leviathan. Hobbes described a picture of social order where the child is considered powerless. Knowledge gives parents the power to rule and this changes only when children finally become parents themselves. Children's play, if not restrained by adults, would threaten the civilisation process of the child and, therefore, free play needed to be averted. Despite the popularity of these Puritan notions, more liberal concepts of children's play began to emerge, evidenced by the founding of the first Kindergarten by Friedrich Fröbel in 1840 (Michaelis and Moore 1891). However, from the beginning, playgrounds were designed to influence children's socialisation and education. Although these spaces were reserved solely for children they could easily be controlled. Towards the end of the 19th century, progressive concepts had gained recognition.

1.2 Educational idea of play

Jean Piaget (1896-1980), a developmental psychologist, promoted the educational idea of play to the broader public by emphasising how important childhood is for human development. Social interaction takes a central role in his theory, as cognitive development is navigated by a social stimulus. Children are viewed as active learners who adapt to their environment through the process of assimilation and accommodation (Piaget 1945). Publications on childcare by psychologist Arnold Gesell (1943) and psychiatrist and paediatrician Benjamin Spock (1946), supported this theory.

1.3 Child-centered play

In the 1930s, new playground concepts facilitating child-centered play were promoted in Sweden, Denmark, and Holland. Carl Theodor Sørensen, a Danish landscape architect, designed urban playground space as natural rural spaces (Kreutz 2017). To encourage children to make their own use of the environment, he integrated swings or a climbing tree at most. Although these places for children met with disapproval from parents - the children got too dirty while playing - Sørensen promoted public green spaces and their social function (Baumann and Wolfs 2018, 57). He developed his ideas further and came up with a junk playground, which later became known as the adventure playground. In 1943, the "Skrammellegeplads" (junk playground) where children were given materials and tools for building and shaping the area, was brought to life in Emdrup, a suburb of Copenhagen, with 700 family homes. Marjory Allen, an English landscape architect and playground pioneer, brought the idea of the junk playground to London in 1946, naming it Adventure Playground (London Play 2012, Soames, n.d.). Other playground ideas included the first abstract play sculpture, erected in the City Park of Stockholm, Sweden in 1949. Møller-Nielsen a Swedish-Danish artist was the first to combine abstract art and play in public space. He not only introduced abstract art in public space to a wider public but also generated a boom in playground sculptures (Baumann and Wolfs 2018).

1.4 The 1960s and Rousseau

The political movement of 1968 towards a self-empowered society influenced the idea of childhood, environment, and education. The understanding of childhood and the role of play within was the theoretical heritage of Jean-Jacques Rousseau, a French Philosopher (1712-1778), who saw children's uniqueness expressed in free natural playfulness based on their intrinsic positive values. Civilisation for him was a corruption of the child's natural innocence. Rousseau believed that children have their own rights, needs, and desires, needing safety and time to grow up healthy instead of paternalism and punishment (Rousseau 1762). This belief influenced the pedagogical principles of the 1968 movement, focusing on child raising without disciplinary elements. Public space was regarded as a democratic space where anti-institutional ideas were tested.

1.5 Safety

The 1980s brought safety standards for playground design and equipment. The Handbook for Public Playground Safety by the U.S. Consumer Product Safety Commission was published in 1981, bringing major changes for companies producing playground equipment. A Eurocode, defining the basis of structural construction products, followed in Europe in 1990 (European Committee for Standardization). Although not legally binding (Commission

of the European Communities 2003), these guidelines became standard in liability cases. Since then, playground design has been restricted by norms for safety. Parental attitudes concerning the safety of children's outdoor play and in playgrounds have changed as well. Beck (1992) calls this phenomenon "the risk society", where parents regard the world outside home as dangerous. Children´s mobility became restricted to shield them from physical harm caused by traffic and unspecific threats he calls "stranger danger". Furthermore, as Rose notes,

> childhood is the most intensively governed sector of personal existence … to ensure its normal development, to actively promote certain capacities of attributes such as intelligence, educability and emotional stability (Rose 1990, 121).

However, the same decade brought the Convention for the Rights of the Child (United Nations 1989) to life, regarding children as individuals with civil rights, needs, and the right to be heard, underlining children's autonomy and agency. Although initially contrary, the power structure and interests that have formed these decisions concerning children have some similarities. These include the aspect of control of children and the question of who has the power-knowledge (Foucault 1976 in Gordon and Foucault 1980). This should be our focus when we try to understand the role of playgrounds for children's right to play.

2.0 FREE PLAY

2.1 The child's right and need to play

The child's right to play is stated in Article 31 of the United Nations Convention on the Rights of the Child (United Nations 1989). The organisation International Play Association, describes play as a form of communication and expression, combining thought and action; it gives satisfaction and a feeling of achievement. It is also instinctive, voluntary, and spontaneous (IPA 1979). It is not controlled by adults. Children's enthusiasm, will, and desire to play are essential to children's cultural worlds. The latter distinguishes children from adults and

> represents one of the most distinctive features of childhood. It is something that children across the globe have in common (Woodyer 2013, 55).

Presumably, adults' perspective on children's play emerges from their own physical childhood experience, and through literature, toys, media, and advertising. Childhood is a common biological experience that changes over time and once we reach adulthood, it is a state we cannot return to. As time passes, adults may no longer be able to recognise important features of children's play. Sociocultural research shows how the world around us shapes childhood and play. Sociologists look at children as a group to understand how they engage with society. To them, childhood is a social construction, shaped and understood by culture (James, Jenks, and Prout 1998).

2.2 Features of play

How can adults recognise children's play? Our understanding of play stems from research on mammals. Fagen (1981) found that play helps animals to adapt to the environment to which they are exposed and therefore is an activity to improve behaviour and learning which impacts evolutionary processes over time. Burghardt (2014) further defined features of play, as a non-functional behaviour that is different from adaptive versions in structure, context, and the stage of development. It takes place when the animal is relaxed and unstimulated. However, play and its recognition is a complex concept of attitudes, behaviour, and feelings (Andrews 2015).

It can furthermore be viewed through different lenses, such as the educational, psychological, feminist, or sociological. Playgrounds are a feature of the built (cultural) environment. They are public spaces for social activities. The sociocultural approach focuses on the social activity of play concerning people and the cultural environment in which it takes place. This approach has been chosen here to investigate the role of playgrounds for children's cultural worlds within the built environment.

3.0 CHILDREN'S CULTURAL WORLD

3.1 Play and culture

The sociologist William Cosaro has researched children's play and cultural worlds extensively. Corsaro believes that "children create their own unique culture" (2012, 488) and that society and culture affect the way children experience childhood. Play is a part of this culture that emerges when children share, negotiate, and interact with their playmates and with adults. To him, children live in two cultural worlds (Corsaro 2012). Firstly, they live in the adult culture of the society they are members of. This is a social construct of commonalities expressed by elements such as music, dance, literature, and architecture linked to cultural heritage and diversity. It implies that culture is made up of "the shared values of a group or of society" (Hall 1997, 2) and that it is "a tendency across disciplines, rather than a discipline itself" (Miller 2001, 1). Secondly, children are members of their own peer culture in which they interpret adult culture by actively using, altering, and expressing aspects of it for their own concerns within their play (Corsaro and Eder 1990). Corsaro calls this process "interpretive reproduction" when children not only adopt cultural aspects from the adult world but also contribute to these aspects. Both cultures relate to one another. Children's peer cultural world although interwoven with adult culture, is equally important.

3.2 Children as social agents

He, like Mayall (2000), views children as agents, someone who negotiates and interacts with others, intending to make change. Mayall (2000) regards children as being part of the social order and asks us to recognize children's contribution to society and their ability of relationship building in families. Within this sociocultural discourse, childhood is more than a period when children grow up to become adults, but a time when children create their own culture and through this impact society. Corsaro and Mayall regard children as human beings rather than human "becomings" by valuing their potential in their present being, rather than in the future as adults. Approach-avoidance

play and dramatic roleplay reveal how children form culture when they communicate with peers during play. The approach-avoidance play

> demonstrates how children cope with real fears by incorporating them into peer routines that produce control (Corsaro 2012, 494).

It enables children to engage in play sequences, confronting fear and anxieties (Marshall 1976; Schwartzman 1978). A well-known example of it is the "run-and-chase game that includes one child taking on a threatening role" (Corsaro 2012, 502), responsible for catching and eliminating players from the game. Dramatic roleplay allows children to slip into social roles, acting out adult features of power, status, gender, and control. Through play, children learn to understand social conventions and relationships. By trying out aspects of elaboration within their play, they refine social roles for their means and construct their roles through interaction with peers and adults.
Children as agents of their concerns use the cultural world around them to remix and interpret fragments of it. This forms their cultural world and, finally, changes the original cultural source.

If free play is so important in children's development, we must look at the one space where they should be able to play freely to see if it provides the appropriate conditions to foster play. We must also consider how both the cultural worlds of adults and children might change in future due to children's interaction with outdoor space in cities, in this case, the playground.

4.0 CHILDREN IN OUTDOOR SPACE

4.1 Features of child-friendly environment

A study on child-friendly environment (Kytta 2004) reveals the interrelation between the resources and options, or affordances (Gibson 1979) of outdoor space and the level of children's independent mobility if space was to be attractive for children. The research group consisted of 223 eight and nine-year-old and their parents, inhabitants of neighbourhoods with different urbanisation levels, who participated via questionnaires and interviews. Kytta's findings indicate that the combination of affordances of space and the degree of independent mobility is an essential indicator in the assessment of child-friendly environments. Urbanised areas were regarded as significantly less child friendly. Also, sociocultural factors designating use of space can block children's play activity. Space with one-use option only, such as gardens (fear of damage to plants or flowers), is a far less child-friendly environment for play than space that offers alternative use like a sports field (Holloway and Valentine 2000).

4.2 How do children engage with playground space?

Brown and Burger's (1984) analysis of research on playgrounds between 1968 and 1981, focusing on free play of preschool children, showed that it was not the design of playground furniture, nor the material of it that brought more "desirable social language or motor behaviours", but design that created zoning, offering encapsulated space and materials children could integrate into their play (599). Playground design is important for the promotion of children's play acts, but children prefer outdoor space to playgrounds if both are available. Where playgrounds are located and how accessible they are within an urban design scheme has an impact on the frequency of use. Safety in children's free play is an important factor for accident avoidance, but this means as safe as necessary and not as safe as possible (Brussoni et al. 2012). If locations offer poor natural lighting due to surrounding high buildings, have a lot of traffic, and uniform ground material they tend to stay unused (Brown and Burger 1984). Research by Barnett and Kruidenier (1981) proved that when playgrounds offer children visually enclosed play space, such as tall grass, bushes or even play furniture that facilitates hiding, more cognitive and socially complex behaviour can be seen in their play.

Childhood educators Deniz and Kalburan (2023) studied the quality and risky play options of 8 neighbourhood playgrounds and 8 green playgrounds in Hamburg, Germany. The green playgrounds were mainly located in parks or natural areas and characterised by trees, bushes, and water elements, while the neighbourhood playgrounds in densely built-up urban areas were smaller, had standardised play equipment and fewer natural elements. The researchers developed a "Risky Play Opportunities Form" for observations and used the 7 Cs Scale (Herrington and Lesmeister 2006, explained by Hansen Sandseter 2007 and supplemented by Kleppe 2018) as a benchmark to detect the visual features of the playgrounds. The 7-point scale connects the physical condition of playgrounds with the knowledge of child development and considers factors such as the relation of the play space to its surroundings, the ease of navigation within the space, opportunities to engage with and leave traces on the space, and the availability of different levels of risky play.

Deniz and Kalburan's findings were that the green playgrounds scored higher in 6 of the 7 criteria. The exception was connectivity, meaning the visual and physical connections of play space and different zoning within. The most important features are defined entrance and exit areas, and a clear path layout helping children to find orientation and to connect cognitively with the features around. In this point neighborhood playgrounds scored higher than green playgrounds. This suggests that playgrounds with nature-related elements and areas have higher quality, but that their accessibility and mobility options need to be carefully reconsidered.

4.3 Benefits of playing in nature

According to Gerald Hüther (2008), a German neurobiologist, experiences in social relationships (e.g., children's play) impact the neuronal structure of the brain, which helps humans cope with problems and challenges over the lifespan. Physical spaces where children play strongly mould the development of the infantile brain. Children who play in an environment that offers diverse nature-related and alterable surroundings develop more creativity and personal responsibility. Playing outside is decisively different when it takes place in an environment where not everything is man-made like in the home. Fabricated toys and technical games include guidelines and reduce

imaginative play, while contact with nature and living creatures raises the interconnectedness of the prefrontal cortex. This impacts cognitive functioning skills like sympathising with others, controlling own actions and regulating frustration and aggression. Also, self-worth and independence increase when children engage in play and exploration of nature (Nilsen 2008; Gebhard 2008). Free play in nature encourages children to develop democratic values (Aasen et al. 2009).

What does this mean for playground quantity and design in cities? Should we rewild play spaces to allow children to find a resource for imaginative and physical play? Furthermore, would building regulations allow us to create such a space?

5.0 BUILDING REGULATIONS

5.1 Playgrounds in Germany

The urban playground is a public space, mostly owned by the City Council, and which should, therefore, be a democratic space where different social groups mix and feel welcome. It should facilitate children's physical and imaginative play. However, when we look at playgrounds in urban settings in Germany, it is striking how stereotyped in their design many of them are. The space is often equipped with similar play furniture, some of which depict themed worlds or provide movement stimuli. These include swings, slides, see-saws, and climbing frames. If sports facilities are available, they are mainly limited to table tennis, football, and basketball. Sensorial stimuli are limited as flooring materials are mainly stone, sand, grass, chipped wood, or fall protection mats. While efforts have been made to diversify building materials, rearrange play equipment, and improve the overall design, most playgrounds appear more a product of safety concerns (German Institute for Standardisation 2017, 2018, 2020) where children are guided to follow the laid-out path, than an environment where children can interact freely with the space or nature. When constructing housing units with more than three flats, the Federal Building Code (2017, para. 9, no. 5) mandates the inclusion of playgrounds in the development plan. In North-Rhine Westphalia, the state with the highest density of large cities in Germany, with over 18 million residents (Federal Statistical Office 2022), a communal building regulation (Ministry of the Interior of NRW 1974) defines the location, size, equipment, and maintenance of children's play areas. The living floor area and the population density are used to calculate the size of playgrounds (section 3).

However, city populations are growing rapidly - the state capital Düsseldorf has grown by over 50,0000 since 1978 (Kerl 2023). With more people living in less space, the basis for calculation is out-dated and does not reflect the necessary space requirements for playgrounds. Urban land in Germany's major cities is expensive and is sold to investors at the highest prices, while playgrounds, the responsibility of the city, cost money and need maintenance. Unfortunately, it has become an accepted practice to allow exemptions from planning regulations that can further reduce playground space in cities. Instead of building playgrounds on their sites, investors can seek permission to pay for the redevelopment or restoration of existing playgrounds in the neighbourhood. Thereby, they avoid reducing the number of housing units as outlined in the building regulation. This results in less outdoor space for all inhabitants and fails to meet children's needs. Also, it illustrates how urban planning regulations play a decisive role in playground location, quantity, and design.

CONCLUSION

Research has shown that outdoor play is critical for children's physical, intellectual, cultural, and social development. Playgrounds, the only place for urban children to play freely, are insufficiently accessible to them due to urban design (Kytta 2004). Existing playgrounds are designed with a focus on safety and developmental concerns.

Despite the shift in the 1990s towards understanding children as equal members of society whose needs are heard and whose opinions are considered in decision-making, current planning regulations still support adult and institutionalised control over urban spaces designated for children.

The cultural world of children today is shaped by adults based on their interests and cultural viewpoints. Corsaro reminds us that children create their own cultural world which feeds back into adult culture. Imaginative free play is an important feature for children to act out this agency. To do so unsupervised, nature-related outside space is needed and must be supplied by city councils. Existing planning procedures ignore children's agency and contravene children's right to play (United Nations 1998). Urban planning authorities need to understand how significant public space is in forming infantile culture and how society can benefit from sociocultural processes that are initiated by children. We are currently failing to provide children's needs for free play space in cities. Policy, urban planning, and practice ignore this fundamental feature of children's lives by destroying children's space through intensive planning and selling of public grounds for economic interest. Public spaces for play need to stay public property. More space for free play is needed and existing playground spaces need protection.

Therefore, our notion of the playground as it currently stands, needs to be reassessed. We need a sustainable discourse on public space to recognise the cultural losses due to past planning decisions and to be able to firmly place play at the heart of future urban design. However, ideas to improve and gain space for outdoor play in cities will not be found by authorities and planners alone. Research from sociocultural fields must be included.

Findings on how children engage with the outdoors (Barnett and Kruidenier 1981; Holloway and Valentine 2000; Kytta 2004; Gebhard 2008; Brussoni et al. 2012) show the interrelation of accessibility, safety, affordances and space qualities. It can serve as one base for a child-friendly environment. Researching the history of urban structures, such as the playground, and verifying whether they are still conducive to our current knowledge and cultural needs is essential to create progress. Urban planners and architects need grounded education when

planning with and for children. To create shared knowledge that can be put into practice, architectural education must change. The architectural curriculum should be supplemented by incorporating findings from childhood studies, including experts and children.

This paper aims to show that a solution cannot simply be found by building new variations of existing playground designs. Instead, to find solutions, different collaborative teams need to be formed at universities, in planning teams, and in city councils dedicated to public space for free child play.

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The experience of space: A sensorial analysis of the Chapelle Notre-Dame-du-Haut by Le Corbusier (1955) and Bruder Klaus Field Chapel by Peter Zumthor (2007)

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ABSTRACT: Although Le Corbusier and Peter Zumthor belong to different generations and their work addresses different issues, both establish connections with the world of the arts and share a concern for the space experience. Given today's dominance of psychological awareness, research on spatial experience is pertinent for contemporary architectural practice.

This paper will analyze the Chapelle Notre-Dame-du-Haut by Le Corbusier (1955) and the Bruder Klaus Field Chapel by Peter Zumthor (2007). The aim is to explore the influence of art on the designs of both architects. Le Corbusier will be examined through his connections with the sculptor Joseph Savina, while Peter Zumthor will be explored through his close relationship with the work of Joseph Beuys. The study of the theoretical work of each author and the analysis of the graphic documentation of each chapel will provide a deeper understanding of how Le Corbusier and Zumthor responded to a shared concern: the experience of space and its relationship with art.

The methodology used in this research integrates various documents, such as the theoretical works of Le Corbusier and Peter Zumthor and documentation from both chapels. The findings of this research enable an understanding of how Le Corbusier and Peter Zumthor respond to a similar concern, wherein art plays a significant role in the experience of space. This research will further contribute to the unexplored relationship between the two architects regarding their awareness of spatial experience and the emotions evoked in individuals engaged within these spaces.

KEYWORDS: Spatial experience; Le Corbusier; Peter Zumthor; Chapelle Notre-Dame-du-Haut; Bruder Klaus Field Chapel

INTRODUCTION

Recently, several architects have expressed concern about the sensorial experience of space, addressing the topic both in their architecture and research (Mallgrave, 2010). However, it is crucial to highlight that this subject has also been explored internationally by renowned architects such as Le Corbusier and Peter Zumthor. This approach is evident both in their architectural and theoretical works (Le Corbusier 1946; Zumthor 1999). When analyzing the architectural production of these architects, one sees that they share the same epistemological and metaphysical concerns (Labbé 2012; Lee 2022). However, there is limited information supporting he idea that art or artists serve as a significant reference by shaping the sensory experience of space, despite both architects acknowledging this influence. The lack of information on this topic makes this essay important, as it provides this perspective on the influence of art in the work of Le Corbusier and Peter Zumthor. This analysis will contribute to a deeper understanding of how such an influence affects the sensory experience of space.

Le Corbusier, in addition to being an architect, was also a painter, sculptor, urban planner, and theoretician. His architecture expresses an approach to the arts, visible throughout his life. Early in his career, with the purist movement and the founding of *L'Esprit Nouveau* between 1918 and 1920, the architect expressed his interest in the connection between architecture and painting (Le Corbusier 1920; Ozenfant e Jeanneret (Le Corbusier) 2005). Later, with *L'espace indicible*, he advocated for the rapprochement between painting, sculpture, and architecture.
Le Corbusier's engagement in various artistic fields makes his work a particularly relevant case study. Several artists have influenced his practice, and one of the most common comparisons is between Le Corbusier and Picasso or Le Corbusier and Fernand Léger (Sales 2012). However, in none of the cases is the direct influence on the sensorial experience of space in Le Corbusier's work is made explicit. In the case of the Notre-Dame-du-Haut, one of the architect's most iconic works, the influence of Josep Savina is evident, particularly concerning the evolution of *L'espace indicible* (Moneo 2022). Without Savina, Le Corbusier would not have been able to design the chapel as we know it today. Savina, thus, becomes a pivotal reference for the chapel, given his direct influence on Le Corbusier's work, by collaborating with him during the period in which he developed *L'espace indicible* (Calatrava et al. 2023). First, through the transposition of Le Corbusier's paintings into sculpture, and later, through his influence on Le Corbusier's working process. The analysis of Savina becomes essential in this essay since the sculptor was present during the period of transformation of the architect's work, which is precisely focused on the sensorial experience of space (Moneo 2022).

Peter Zumthor, although not a painter or sculptor like Le Corbusier, approaches his work with a strong connection to the arts. He states that his approach to architecture involves learning it outside of traditional architectural boundaries (Architecture Speaks 2018). Similar to Le Corbusier, who began his education in arts school rooted in the "learning by doing" method, Zumthor started working as a carpenter at a young age under the guidance of his father. This early experience fostered his approach to manual labor and cultivated his sensitivity to materials and composition (Ventura 2014; Zumthor 1999). Zumthor's work is often linked to the philosophies of Heidegger or Pallasmaa, who explore the experience of space through emotions and sensations (Labbé 2019). Two key references for this perspective are his books *Thinking Architecture* and *Atmospheres*, as both address these themes. However, when considering the influence of art or artists on his work, only a few figures stand out, such as Richard Serra or Michael Heizer (Kimmelman 2011). In the case of the Bruder Klaus Field Chapel, Joseph Beuys stands out as particularly notable for his sensitivity in the treatment of materials - an aspect that also characterizes Zumthor's architecture (Zumthor 2006). In Zumthor's case, Beuys's influence differs from that of Le Corbusier and Savina. Beuys indirectly influenced his work as an independent artist. Zumthor admires his work, understands it, and therefore, interprets it within his architectural practice.

Le Corbusier and Zumthor are two important references in contemporary international architecture, and understanding their influences enhances our comprehension of each architect's work. In the context of this essay, the analysis of the impact of artists on the work of Le Corbusier and Zumthor offers a reflection on the transdisciplinary nature of architecture as a field of knowledge. Understanding the references of each architect's approach is crucial. Furthermore, identifying the contribution of each artist helps clarify their influence on the sensory experience of the space.

1.0 RESEARCH METHODOLOGY

The research explores the sensory experience of architecture by emphasizing the influence of art. Le Corbusier with the Chapelle Notre-Dame-du-Haut (1955) and Peter Zumthor with Bruder Klaus Field Chapel (2007) are the two case studies for their importance on the theme. Both distinguish themselves through their unique approaches to spatial experience and awareness.

This research primarily employs a qualitative methodology to facilitate the cross-referencing of information from various authors. Given the extensive body of work on both architects, five key points were selected to organize the data collection: i) texts by Le Corbusier and Zumthor discussing spatial experience and emotions; ii) texts by both architects exploring the relationship between architecture and the arts; iii) texts by both architects specifically describing the Chapelle Notre-Dame-du-Haut and Bruder Klaus Chapel; iv) texts from various authors analyzing the case studies;

To analyze the data collection, tables and panels were created to facilitate the exchange of information between the two architects and resources. Although the research is mostly based on textual information, a panel was created to allow the analysis of visual elements adopted by both architects. Whether elements from tradition or elements from their architectural language. Data collection used in this research can be found in: i) archives and online resources; ii) books from Le Corbusier and Zumthor; iii) books from different authors; iv) interviews in online resources; and v) visits to the case study sites.

All the research was conducted ethically with full respect for the authorship of all architects and authors. Textual and visual information was appropriately cited, and interviews, archives, or online resources were clearly attributed to their respective authors.

2.0 CASE STUDY ANALYSIS – Le Corbusier

2.1 Le Corbusier: The Chapelle Notre-Dame-du-Haut, 1955

Le Corbusier is regarded as one of the most significant architects of the Modern Movement (Benevolo 1960). His work is defined by a constant pursuit for harmony through the sensorial exploration of space, where art plays a central role (Le Corbusier 1925).

Associated with this search for harmony, Le Corbusier published *L'espace indicible* in 1946, a space that addresses epistemological and metaphysical questions while advocating for the union of the arts between architecture, painting, and sculpture. This union aimed to transcend the purely visual idea of space towards an ineffable space, the result of plastic emotion (Le Corbusier 1946; Moneo 2022). Among the various works of the architect, the Chapelle Notre-Dame-du-Haut, from 1955, stands out because of its ability to deepen our understanding of his sensorial experience of space. According to Le Corbusier himself, the chapel at Ronchamp demonstrates that "architecture is not a matter of columns but a matter of plastic happenings"(Petit, 2019).

The chapel was commissioned to Le Corbusier in 1950 after the existing chapel was bombed by the German army in 1944. Le Corbusier had previously refused to work with the Catholic Church, but, given the formal freedom of the commission and landscape, he accepted the project. (Petit 1997) At the top of a hill in Ronchamp, the Chapel is surrounded by nature (with some later construction from 1970 and 2011 by Jean Prouvé and Renzo Piano). In terms of typology, the Chapel respects the plan of a single nave, with the apse facing east. Outside, each facade is unique, with elements that characterize it. On the south facade, the main entrance, with a 3-meter-thick wall and openings with colored glass. The east facade, an exterior altar receives around 200 pilgrims, while echoing the

interior altar on its reverse side. On the north facade is the secondary entrance with two adjoining chapels. The west facade, the only blind facade, has a gargoyle that drains water from the roof and a cistern. Finally, the roof is one of the most emblematic elements (Boesiger 1958b). It is important to emphasize that, when designing the Chapel, Le Corbusier used several references that were adopted over time, such as *objets à reaction poètique, the* use of elements from tradition, and elements from memory (Le Corbusier & Pauly 1983).

About his references, Le Corbusier maintained contact with several artists who influenced his work, such as Picasso, Rouault, Matisse, and Fernand Léger. In the case of the Chapel, the cabinetmaker and sculptor Joseph Savina stands out for his collaboration during the development of *L'espace indicible*. Savina respected the vernacular manual tradition, and his impact on Le Corbusier's work is visible in the reconciliation of the artist-artisan (Calatrava et al. 2023). The collaboration between the two artists began when Savina suggested working on the three-dimensionality of Le Corbusier's paintings. (Moneo 2022) This led to a collaboration between the two artists with polychrome sculptures such as *Ozon, Totem, Ubu, Icône, La mer,* and *Femme.*(Calatrava et al. 2023; Moneo, 2022) Among these works, Frampton highlights *Ozon* and *Ubu* for enabling the development of what would be his 'visual acoustics' of landscape. (Frampton 2001) Visible in the design of the roof, gargoyle, chapels, and altar. (Frampton 2003) Le Corbusier, when referring to the 'Phenomenon of visual acoustics', the architect affirms:

> On the hill, I had meticulously drawn the four horizons. There are only four: to the east, the Ballons d'Alsace; to the south, the last spurs leave a vale; to the west the plain of the Saône; to the north a small valley and a village. These drawings are missing or lost, it is they that unlocked, architecturally, the echo, the visual echo in the realm of shape. On the 4th June 1950… Give me charcoal and some paper…(Le Corbusier 1957)

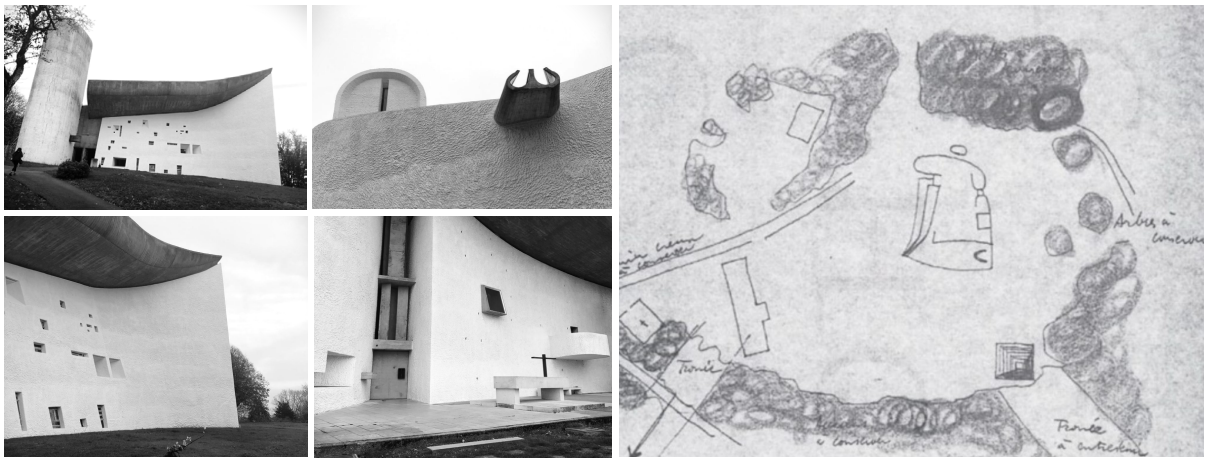


Figure 1: Le Corbusier, Chapelle Notre-Dame-du-Haut, 1950-1955 (Photos from the Author); Drawing by Le Corbusier, FLC 07514C 1959, © F.L.C. / 2025, ProLitteris, Zurich. Source: (Author 2022)

2.2 Findings: Spatial experience, Le Corbusier, and Joseph Savina

The period during which Le Corbusier collaborated with Savina corresponds to a transformative phase of his work, particularly concerning the union of the arts and the definition of *L'espace indicible*. This period enabled him to deepen his exploration of his great *interest in psycho-physiological reactions in man* (Boesiger 1958a, p. 227). But how did *Ozon* and *Ubu* influence the chapel's design? Let us return to Frampton's affirmation and the design of the roof, gargoyle, chapels, and altar.

Moneo, while describing the working process between Le Corbusier and Savina, states that the monstrous forms of *Ozon* appear to come from nature and are subject to a process of biomorphism. (Moneo 2022) It is, therefore, possible that in the design of the chapel, Le Corbusier subjected the roof to a process of biomorphism and abstraction, which distanced it from the original shape of the crab shell, captured in 1946 during a trip to New York (Le Corbusier 1957). Another possibility is the fact that this reference influences not only the form but also its concept. According to Pauly:

> This crab's shell not only inspired him conceptually in the shape of the roof – an organic form to match the organic plan – it also generated the idea for the roof structure itself." (Pauly 1997, p. 90)

In the case of the gargoyle, Quetglas states that its shape is inspired by the series "Les Taureaux", which was also explored in Le Corbusier's painting (Quetglas 2022). This demonstrates a plastic exploration from painting to architecture. The chapels, which illuminate the interior space thanks to overhead light, refer to the projects of Villa Adriana, although with slight modifications in their configuration (Petit 2019). Moneo goes further by emphasizing that the chapels are the elements that bring Le Corbusier closest to his working method with Savina due to their iconographic autonomy. He also highlights other equally important "elements", such as the gargoyle (Moneo 2022). The altar, unlike traditional altars, exists in dialogue with the interior altar, separated by a concave and convex wall, which allows the repercussion of sound (Moneo 2022).

When analyzing the elements that Frampton describes – as a result of the influence of *Ozon* e *Ubu* - it is possible to identify an influence on the creative process. In the same way that Savina reconstructed Le Corbusier's paintings into sculpture, the architect uses other artistic references, travel souvenirs, drawings, or objects, which are then adapted to his architecture. While Savina transposes painting to sculpture, Le Corbusier's approach is much more complex, calling on different references that would not initially be interconnected in another context. The chapel is one of Le Corbusier's most important works in terms of the sensory experience of space. (Moneo 2022) Savina's influence on this theme does not have a linear and literal form. The architect does not adopt a form of *Ozon* e *Ubu* and integrates them into the design of the Chapel. But first, he understands the possibilities of the working process that he develops with Savina during the period in which he develops these works and adopts it on an architectural scale. In this approach, Le Corbusier included other references besides painting and sculpture, which ultimately determined the design of the chapel and, therefore, influenced the sensory experience of space.

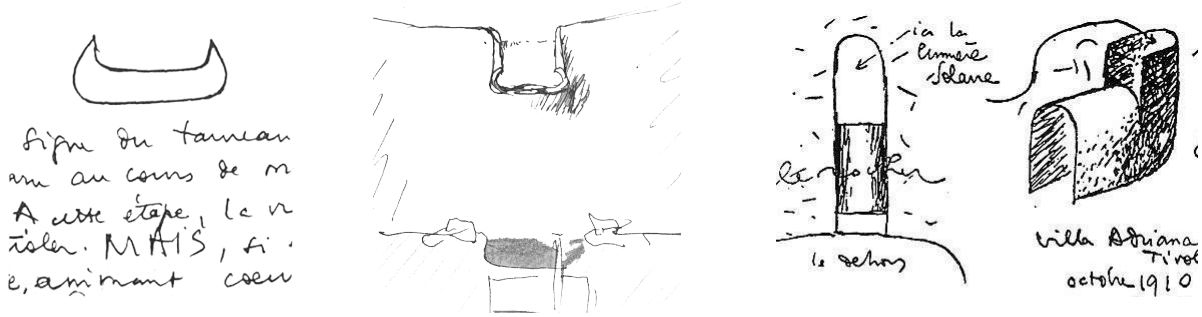


Figure 2: Le Corbusier, drawing “Entre-deux ou propos toujours relies” 1964; Le Corbusier, FLC_CA_E18, 1951; Le Corbusier, Villa Adriana FLC P5(2)10 1910; © F.L.C. / 2025, ProLitteris, Zurich. Source: (Author 2025)

3.0 CASE STUDY ANALYSIS – Peter Zumthor

3.1 Peter Zumthor: Bruder Klaus Field Chapel, 2007

Like Le Corbusier, Peter Zumthor is a significant architect who focuses on the emotional awareness that arises from architectural experience. This concern is evident in both his writings and architectural work, mainly through his use of materials, references, and ideas. Unlike Le Corbusier, Zumthor does not engage in painting or sculpting; however, his early experience as a carpenter gave him a heightened sensitivity to composition and harmony. While many architects discuss the experience of architecture through atmospheres, Zumthor distinguishes himself by exploring this concept in a poetic dimension. For Zumthor, learning architecture doesn’t come exclusively from architectural experiences but also from other fields (Mallgrave 2010, p. 189). The architect asserts that for him, learning architecture was a process of learning outside of architecture. This means to learn from other fields such as music, painting, or even arts (Architecture Speaks 2018).

The chapel was commissioned to Zumthor and constructed between 2005 and 2007 in Mechernich, Germany. Situated in a rural area, the chapel stands out for its unique presence amidst the surrounding vegetation. Its typology evokes the central plans of some Romanesque chapels, featuring overhead light and thick walls. While it does not entirely blend with the environment, it adopts the tones of the pasture and the land. The Chapel creates a profound sense of interiority, separating interior and exterior worlds, whether through light, sound, or temperature. It lacks direct windows, yet the light has a *chiaroscuro* treatment that allows the light to penetrate indirectly. Regarding materiality, the chapel is entirely constructed in concrete, with a finish that emphasizes its rough texture (Vandenbulcke 2014). In the chapel, Zumthor reduces the elements to the essentials: a cross, a small bench, an oratory area, and a bust (Byrne 2018).

In his book *Atmospheres*, the architect describes twelve factors that influence and characterized his architecture, including: i) the body of architecture; ii) material compatibility; iii) the sound of Space; iv) the Temperature of Space; v) Surrounding Objects; vi) Between Composure and Seduction; vii) Tension between Interior and Exterior; viii) Levels of Intimacy; ix) the Light on Things; x) Architecture as Surroundings; xi) Coherence; xii) The Beautiful Form;(Zumthor 2006)These aspects are evident in the chapel, alongside elements drawn from memory and tradition (do Valle Zonno 2020). Literature refers to these points as references to understand Zumthor’s work. However, it became unclear how art influenced his work, even though he manifested his interest in many American artists from the '60s, '70s, and '80s (Kimmelman 2011). One of the artists who seems to have an enormous influence on his architecture is Joseph Beuys, particularly for his treatment of materials and the processes involved in this treatment:

> Something is revealing about the work of Joseph Beuys and some of the artists of the Arte Povera group. What impresses me is the precise and sensuous way they use materials. It seems anchored in an ancient, elemental knowledge about man’s use of materials, and at the same time exposes the very essence of their materials which is beyond all culturally conveyed meaning. I try to use materials like this in my work. I believe that they can assume a poetic quality in the context of an architectural object, although only if the architect can generate a meaningful situation for them since the materials themselves are not poetic. (Zumthor 1999, p. 10)



Figure 3: Peter Zumthor, Bruder Klaus Field Chapel, 2005-2007. Source: (Author 2025)

3.2 Findings: Spatial experience, Peter Zumthor, and Joseph Beuys

Joseph Beuys stands out among the artists of his time for his partisan activism and his exploration of materials in his art. (Russell 1986). The artist uses unconventional materials and explores the use of fat, blood, and trees, among other materials (Rosenthal et al. 2004). Beuys aims to provoke society and reflect its social concerns and political beliefs through these materials (Borer et al. 1997). But how is Joseph Beuys present in this chapel, and how does he inspire Zumthor in the experience of space?

In the case of Zumthor's work, Beuys's influence is not seen through the direct adoption of the same materials but rather through the understanding of their potential, expressiveness, and the processual activities associated with them within the broader context of the work. The use of simple materials would allow Zumthor to explore their plasticity in an ancestral way, preserving what would be considered fundamental human experiences (Ventura 2014).

> I saw how Beuys worked, which was a revelation - that Beuys was working with materials, in a way like words and sound, composing in a way with materials, as a message. It was not performed. It was this material, this, and then performed. This struck me as something new, the way you learn something but then think, it is something I always knew, being very subjective is being very objective(Zumthor 2009, p. 51)

In the case of Peter Zumthor's Bruder Klaus Field Chapel, the influence of Beuys is evident in a similar way. The architect uses pure and simple materials, such as concrete, in which his formwork is made with wooden trunks (ZhiXing & Wei 2023). The plasticity acquired through this formwork is the most present aspect of the spatial experience, offering a dialogue between the visitor and the architecture itself. This formwork process is, to a certain extent, reminiscent of ancestral constructions (Jenner 2011). Without other materials, Zumthor conveys the religious message of space through matter, control of form, and light (ZhiXing & Wei 2023). The connection between Zumthor and Beuys may transcend the use of materials. Beuys was not only a sculptor but an active agent with a transversal message in his work, political and social. His art expresses a belief in time changing. Zumthor expresses a belief in sensorial exploration, which is closer to vernacular architecture than to tech architecture.

Looking to the past and preserving space quality (Zumthor & Lending 2018). In the same way that *Beuys' "*extended definition of art" in which the ideas of social sculpture could potentially reshape society and politics, Zumthor's message focuses on metaphysical experiences of how to build and inhabit space as a sensory experience through sensations (Tate Gallery 2024; Zumthor 1999).

> If a work of architecture consists of forms and contents that combine to create a strong fundamental mood that is powerful enough to affect us, it may possess the qualities of a work of art. This art has, however, nothing to do with interesting configurations or originality. It is concerned with insights and understanding, and above all truth. Perhaps poetry is unexpected truth. It lives in stillness. Architecture's artistic task is to give this still expectancy a form. The building itself is never poetic(Zumthor 1999, pp. 19–20).

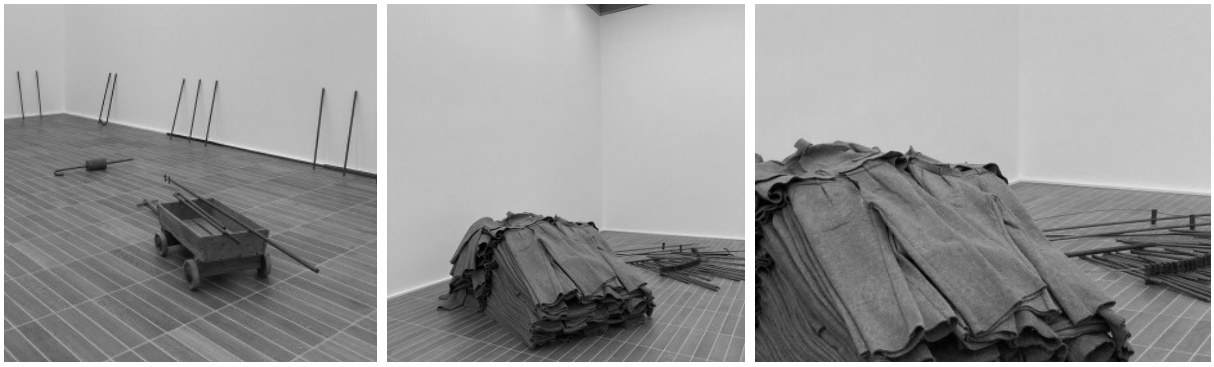


Figure 4: Joseph Beuys, Feuerstätte II, 1978-1979. Source: (Author 2025)

CONCLUSION

This essay aims to analyze how art can influence the sensory experience of space. In the case of the Chapelle Notre-Dame-du-Haut, the influence of the sculptor Joseph Savina is evident, with whom Le Corbusier collaborated during the development of *L'espace indicible*. In the case of the Bruder Klaus Field Chapel, the influence of Joseph

Beuys is also evident, although they did not work or collaborate. Through the analysis of these two chapels, it becomes clear that both architects were concerned with the sensory experience of space.

During the time Le Corbusier worked with Savina, he did not design any buildings. The chapel allowed him to explore his ongoing research focused on the union of the arts, which he was developing at that time (Moneo 2022). Unlike his previous works, where there was a rapprochement between painting and architecture (as is the case of purism, in which he was one of the founders, and the rationalist villas of the 1920s), with the chapel, the architect brings together other artistic approaches and references (Pauly 1997).

Savina played a crucial role in the design of the Chapel, influencing Le Corbusier's working method (Moneo 2022). Together, they transposed the architect's paintings from this period into polychrome sculptures (Calatrava et al. 2023). This exercise allowed Le Corbusier to understand that the shapes from his paintings could transcend the two-dimensionality of the canvas and take on new dimensions. The architect applied this knowledge to the chapel, reproducing different references, such as objects and drawings, which were then transformed and adopted into the work (Moneo 2022). Two emblematic examples of this appropriation are the case of the chapels, through which the architect takes up drawings from past journeys, such as Villa Adriana, as well as the gargoyle that refers to the series of "Les Taureaux" (Moneo 2022; Quetglas 2022). The Chapelle Notre-Dame-du-Haut is considered one of the most emblematic works of the late Modern Movement, both controversial and admired by critics (Jencks 2000). Savina's influence on the Chapel was so important that Le Corbusier highlights it in his book *Oeuvre Complète 1946-1952* (Boesiger 1958a). It seems thus reasonable to conclude that if Le Corbusier had not worked with Savina, he would probably not have developed this working method, which would have resulted in a particularly different conception of the chapel.

In Zumthor's case, admiration for the artist Joseph Beuys is expressed repeatedly, both in interviews and in his writings (Zumthor 1999). Beuys is distinguished by his treatment of materiality as a message. Unlike Savina, who interprets from painting to sculpture and works directly with Le Corbusier, the artist does not work with Zumthor. However, his influence is felt through the interpretation of Zumthor's work. While Beuys expresses his social and political beliefs through art, with materiality playing a central role, Zumthor focuses on understanding the sensory qualities of space through the building processes and the subsequent material expression (Zumthor 2006). Beuys's influence on the Bruder Klaus Filed Chapel is evident not only in the treatment of raw materials, such as concrete, but also in the use of materials that carry a deeper meaning. In response to the chapel's religious program, Zumthor uses materials that allow him the plasticity necessary to evoke the desired spiritual atmosphere (ZhiXing & Wei 2023).

In both cases, in the Chapelle Notre-Dame-du-Haut and the Bruder Klaus Field Chapel, it is possible to identify the influence of Savina and Beuys on the sensory experience of space. On Le Corbusier, a direct influence due to Savina's participation in polychrome sculptures and *L'espace indicible*. With Zumthor, an indirect influence due to admiration for the work of Beuys. Through these two case studies, one may conclude that the integration of artists' knowledge and working methods into architectural design significantly influences the sensory experience of space. Future research could expand on this by exploring the work of other artists and examining the extent to which Le Corbusier and Zumthor incorporated their influences, thereby further influencing the sensory experience of their architecture. This essay also emphasizes the transdisciplinary nature of architecture. A field of knowledge that operates in parallel with other fields, highlighting the possibility for other artists to be able to act directly and indirectly on the design of the architect.

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The Space Groups and Collaborative Assembly

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ABSTRACT: This investigation reviews an unexpected outcome arising from using a tool for algorithmic design for a human fabrication project. The Space Groups are a mathematical system for describing repetitive 3d Unit Geometries commonly used in crystallography. Horta is a Grasshopper library which adapts these methods to define elements within a Unit Cell and output terse instruction sets for distributing these across a lattice to create complex honeycombs. Originally intended for automated assembly in the *Computationally Optimized Robotic Architecture Laboratory (CORAL)*, it was found that Horta also facilitates collaborative human assembly. Workshops were delivered at CAAD Futures 2021 to help educate architects about the use of Symmetries in design - specifically the use of the Space Groups as design tool via the units generated by Horta. The COVID-19 pandemic resulted in the Conference and Software Workshop shifting online. The original design for the Fabrication Workshop was predetermined. Without in-person Conference participants or facilities available, an ad-hoc group of volunteers gathered and through shared effort, an unanticipated potential for discrete modular assembly emerged. When the Workshop goals were simplified, the design became open-ended - the final design emerging bottom-up from the collaborative assembly process. Horta was developed to generate “algorithmic” instructions for automated assembly. However during the Fabrication Workshop it was found that applying this system allowed a “heuristic” collaborative design method to emerge. This opened participation to the untrained, even a child. The algorithmic methods of the system directly facilitated the adaptive heuristic methods of a community fabrication project. This paper briefly explains the Space Group Symmetries and then outlines the Workshops. It finishes by examining the outcomes of the Fabrication Workshop. Both the last-minute adaptation to the pandemic restrictions and the surprise outcome of a heuristically-driven community design effort are apt for examination along the 2024 EAAE-ARCC Conference theme *Architecture Into The Unknown*.

KEYWORDS: space croups, emergent community, algorithmic design, design heuristics, collaborative design.

INTRODUCTION

The Space Groups are a mathematical concept for the categorization and concise description of repetitive symmetrical arrangements in 3d space which is commonly used in crystallography (Klein and Hurlbut 1977, pp. 113-115). Historically, symmetry in architecture has been considered almost exclusively in two dimensions. Horta is a Grasshopper component library which implements the Space Groups for computational design. It was developed by the author to complete the suite of tools necessary for a mathematically rigorous use of symmetry within architecture and is intended for use across design methods and scales. The original use case for Horta is to streamline autonomous fabrication of discrete assemblies. However, an interesting human side effect of this was encountered which is the subject of the current study. This paper begins with a description of the Space Groups and their potential in automating fabrication. It continues to review the Workshop and its unanticipated outputs, concluding with a discussion of these in the context of *Architecture Into The Unknown*.

1.0 BACKGROUND

1.1 Current status

It is important to briefly establish the utility of the Space Groups, which springs from their ability to systematically generate form. This is due to:
1. The unambiguous spatial logic of the Bravais Lattices (Hammond 2015:86-98)
2. The descriptive efficiency of the International Notation System (ibid:114-120)
3. The rigorously repetitive nature of Space-Filling Honeycombs.

The Bravais Lattices are the fourteen distinct Space Lattices: the arrangements of Unit Cells which tile 3d space continuously. "Sub-Cell Units" (aka "sub-units")[1] are the smaller polyhedra whose grouping and repetition are defined within the Lattice. (Figure 2 and 3)

As compared to an assembly of similar form based on individual distinct or random sub-unit variants, a Horta-derived assembly requires magnitudes less information due to the symmetries inherent to the sub-units and the long-range order of the Lattices. (Refer to Section 2.1). However, these units and placements exhibit more novelty than regular lattices or Archimedean honeycombs. The core idea is that generating novelty in computational form-making should not be limited to increased randomness or morphological complexity. By using the generated

polyhedra and defined regular ordering systems together, Horta creates sophisticated forms with compact instruction sets.

1.2. Horta and space group application

Horta was designed to integrate with common Grasshopper workflows. For simplicity, the workshop focused on transforming points then generating the Voronoi polyhedra (Vainshtein 1996: 148.) about each point to create a space-filling honeycomb of these sub-units. The Orthorhombic Crystal Class (Klein and Hurlbut, p.86) is helpful for demonstration purposes as the only one whose International Notation utilizes all three axes {A,B,C} and correlates them to the (x,y,z) of Cartesian space. (ibid:63, Table 2.9)

1.3. Autonomous construction

The first application of Horta has been CORAL, a system to further automate the design and construction of sophisticated forms. In the first decades of the "Digital Era," increases in computing power frequently facilitated increases in the speed, extent, and / or morphological variation possible. Computing was often used in a relatively straightforward manner to extend the capability of design methods which predate the computer. One can see this in the increase the formal complexity made possible as Deconstructivism arose from Post-Modernism in architecture.[2]

More recently this has been challenged by the "Discrete" tendency, in which the fundamental constraints of computers and automated assembly equipment are harnessed via the use of repetitive geometries easily processed by machines. This "machine sympathy" facilitates streamlining these workflows through leveraging the nature of computers and robots as machines with discrete states. But this is not a project to simply replicate these earlier computational models through newer means. In the work of Retsin, Köhler, and others - discreteness generates a new approach to the data and operations of design and assembly. (Retsin 2019: 8-10).

Horta continues this work by extending the aspects of the process to which this model can be applied and the range of units available in these operations while still maintaining terseness in description of the cellular shapes and their relationships to each other. The long-term goal of CORAL is to create a single workflow which builds architecturally scaled objects starting from initial design goals through calculation and fabrication of units on to final placement and attachment (Figure 1). The goal-oriented and evolutionary approaches for describing the assembly allows form to emerge "bottom-up" from the aggregation of the sub-units (as in Section 3.2).[3]

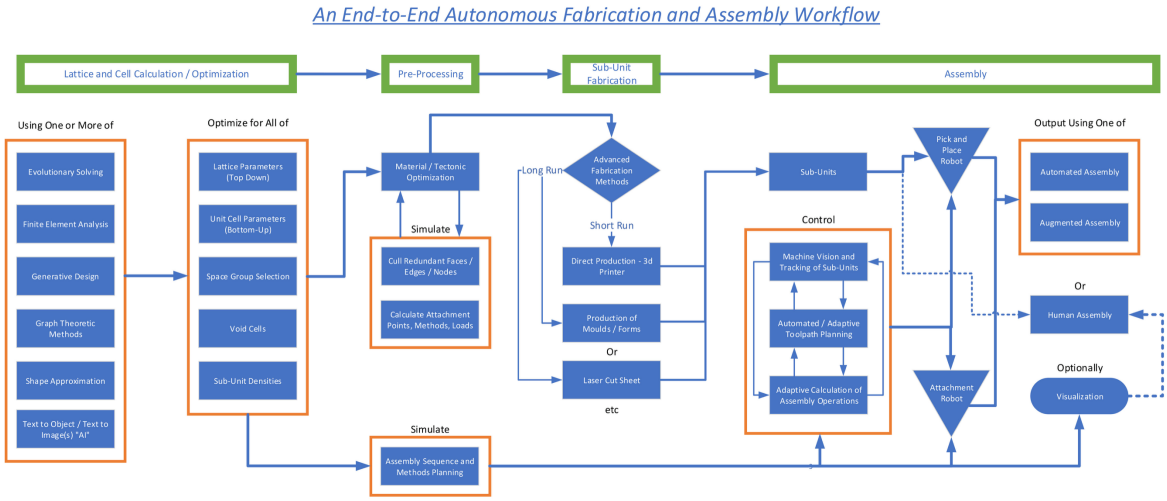


Figure 1: CORAL Workflow Source: (Author 2019-2024)

2.0 METHODOLOGY

2.1. The space groups in the workshops

The software workshop uses a "base case" (Figures 2 and 3) of an Orthorhombic $I6_311$ pattern. (Table 1) A modified base case is used in the Fabrication Workshop. (Table 2) The generation of $I6_311$ is as follows: the volumetric center of the unit cell is used as the root node (I per International Notation). One generator point is placed at the Special Position halfway along the diagonal from *I* to the lower left corner node. The generator point is subjected to the Symmetry Operations in order of the notation - 6_3 in the A direction then *Identity* (no transformation) in the B or C.[4]

I is added to the six generated points and these seven are used to define the Voronoi polyhedron around each point. The result is a honeycomb composed of three topologically distinct sub-units types $\{P, Q, R\}$ with R having two sub-types $\{R1, R2\}$ which are mirror-symmetrical variants. The allowable locations of all sub-units are indicated by the matching of their faces. This property can be used to easily orient a new piece within the honeycomb and

allows this system to be both algorithmically definite (Knuth 1997, pp. 4-5.) for automated fabrication *and* heuristically recognizable (Pearl 1985, pp. 3-4.) for human assembly.

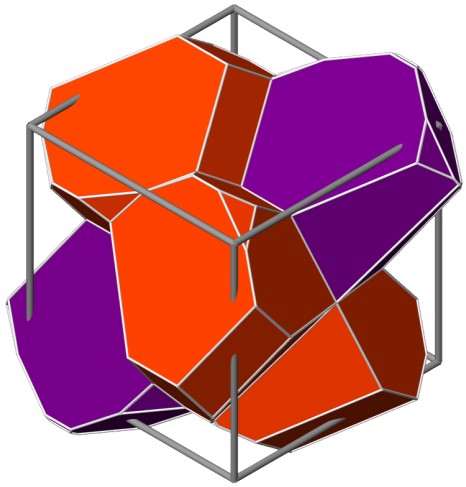


Figure 2: Sub-Units in *I* 6_3 *1 1* Pattern. Soruce: (Author 2023)

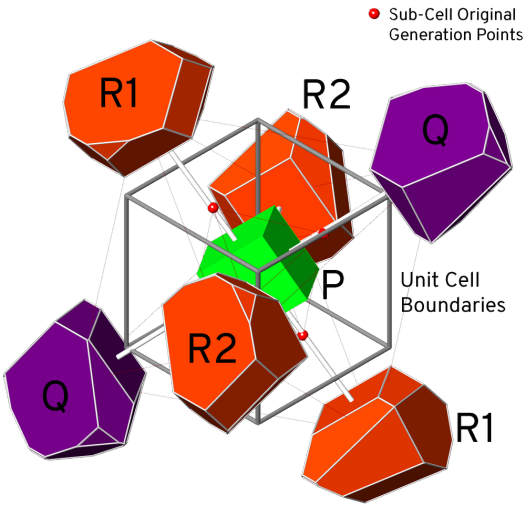


Figure 3: Exploded view of Figure 2. Soruce: (Author 2023)

Table 1: Sub-Units from Figures 2 and 3. Source: (Author 2023)

Name	Polyhedron Type	Faces	Frequency	Notes
P	Cube	6	(1)	Centered at Root Node
Q	Convex Irregular	17	(2)	-
R1	Convex Irregular	14	(2)	Mirror of R2**
R2	Convex Irregular	14	(2)	Mirror of R1**

** Mirror Plane perpendicular to midpoint of line between R1 and R2 generating point in each direction

In the Fabrication Workshop (aka "*Prime*") variant (Figure 4), the generator point is moved 12.5% closer to the root node along the same line. This Unique Position is instructive for demonstrating the impact of Position on symmetry.[5] This preserves shape topology while altering morphology and sub-unit symmetrical relationships, helping explain to participants the various constraints on the operation of the Space Groups.

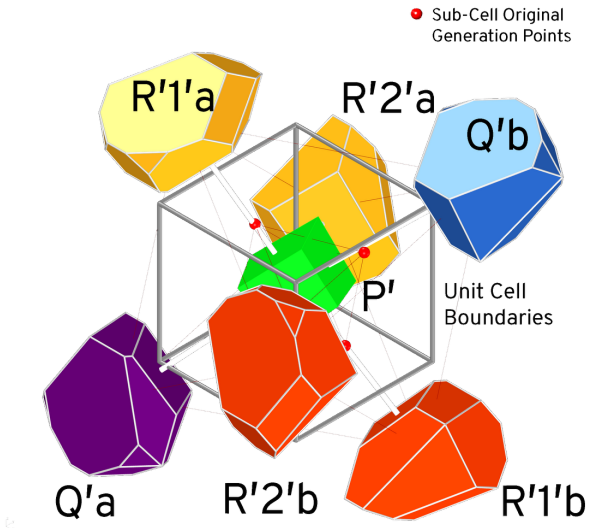


Figure 4: Exploded view of the Sub-Units used in the Fabrication Workshop. Source: (Author 2023)

Table 2: Sub-Units from Figure 4. Source: (Author 2023)

Name	Polyhedron Type	Faces	Frequency	Notes
P′	Irregular Cuboid	6	(1)	Centered at Root Node
Q′	Convex Irregular	17	(1) Q′a (1) Q′b	Q′a and Q′b are isotopic - 12 identical faces
R′1′	Convex Irregular	14	(1) R′1′a (1) R′1′b	***
R′2′	Convex Irregular	14	(1) R′2′a (1) R′2′b	****

*** R′1′ and R′2′ closer to base plane remain mirrored similar to Figure 2, referred to as R′1′a and R′2′a
**** R′1′ and R′2′ further from base plane remain mirrored similar to Figure 2, referred to as R′1′b and R′2′b

The distance from the root node $I$to each group of generated points $\{1,3,5\}$ and $\{2,4,6\}$ is equal but unlike the base case the points in each group are not equidistant from I. The resulting cuboid is slightly deformed, with (2) groups of (3) identical faces. This change results in all sub-units being morphologically distinct but retaining homotopy. The same cut file can be used for the R' figures ending in a and in b when flipped. Each of the other sub-units has slight distinctions in shape.[6]

With all (7) sub-units being morphologically distinct, this is highest degree of variation that can be produced with pattern $I6_3 11$. But even when altered formally, symmetries and homotopies remain between sub-units. Contrasting the base and *Prime* patterns also demonstrates that system variability can be achieved without sacrificing the overall coherence of approach. In sum, the geometries produced by each Space Group will be uniform if the generator points are at Special Positions and will vary within the bound of the largest single number in the International Notation otherwise.[7] These locations are calculable (Sands 1996:75-76) and the impacts are generalizable across Space Groups.

2.2. Software workshop methods

The Software Workshop was planned for "hybrid" delivery. Due to COVID restrictions, the hosting Conference was shifted entirely online and the scope and goals of the Workshops were adjusted. In the Software Workshop the author scaffolded participant learning by building the script for the Installation while they built their own in parallel. Since the directed, node-based nature of Grasshopper requires each step to build upon the last, existing knowledge "telescopes" to build competency and agency with the tool. As compared to script-based programming, the visual feedback given by the Grasshopper environment is also advantageous for this method.

The Software Workshop was 2.5 days long. Day 1 consisted of a lecture on the fundamentals of symmetry, an introduction to the Space Groups and their potential in architecture, and a hands-on tutorial using Horta. On Day 2 the group worked through troubleshooting their scripts and a collaborative Design "Hackathon." This resulted in the generation of sub-unit cut files using other Grasshopper tools. On Day 3 the participants engaged in a reflection and critique of their final designs. Section 3.1 discusses two notable implementations from Software Workshop participants.

Participants were introduced to the methods above and learned to use Horta in standard Grasshopper workflows. In interest of saving participant time and energy, the Workshop focused on generating sub-unit lattices then selecting only those sub-units which intersected with geometries created in Rhino or Grasshopper.[8] The relationship of sub-unit resolution to the original geometries was of particular note. As a system for producing real-world assemblies, the advantages and disadvantages of different scales of sub-unit were examined and discussed. The fitness of various patterns and scales to generate the desired level of fidelity to the base forms was compared by examining the ratio of edge length (for designs constructed from linear elements) or surface area (for designs made from sub-unit blocks) to volume.

For volumetric models, participants then integrated Horta with geometry unrolling and fold-tab creation components in Grasshopper to examine best practices for fabrication from sheet materials. Given more time the Workshop would have also covered the creation of sub-unit lattices from linear elements using joint nodes or miters.

2.3 Fabrication workshop methods

The original outcome of the 3 day Fabrication Workshop was to be a full-scale (≈ 6’ x 8’ x 8’) honeycomb constructed from CNC-cut plywood (Figure 7). Horta and and Grasshopper were used beforehand to generate the sub-units, eliminate redundant faces, and define edge connections. Edges shared between faces were to be milled into "knuckles," with threaded rod and nuts used to create “piano hinge” joints.

After the scale was reduced the same computational concepts were applied to a smaller construction using less permanent materials (Figure 8). “Solidcore” board was procured (at a deep discount), laser cut, then folded into the sub-units. Brass brads were used to attach these face-to-face. The faces redundant in the original design became necessary for assembly, which provided the opportunity for heuristic community construction as described in Section 3.3. The P sub-units were painted blue, Q were cut from white solidcore and R from black solidcore. With the loss of a space and participants from the Conference, a location was secured and a group gathered to collaborate on sub-unit cleanup and construction, categorization, and attachment.

3.0 RESULTS AND DISCUSSION

3.1. Software workshop results

During the Software Workshop, Ghazal Javidan filled volumes with lattices constructed from sub-unit edges defining piped members. (Figure 5). Using Grasshopper, redundant edges were culled prior to geometry creation.

Kevin Flores was already very adept at the Grasshopper environment and was able to create multiple novel approaches. Among others they created sub-unit lattices which could be assembled to approximate minimal surfaces generated by Grasshopper physics-simulation plugin Kangaroo. (Figure 6).[9]

On Day 2 the participants also generated their own cut-files for the construction of these assemblies. However, being isolated at home no participants were able to cut these or build their own real-world sub-unit lattices by the end of the Conference.

The outcomes of the Software Workshop express the capabilities of the Space Groups implemented via Horta to drive variation in design outcomes. The integration of Horta with Grasshopper's existing tools also affords methods for evaluating properties such as material usage and variation from the geometry being sampled. These results also demonstrate that although the Discrete tendency is relatively recent, it is capable of robust and consequential didactic outcomes which help conceptualize the creation of complex form in new ways.

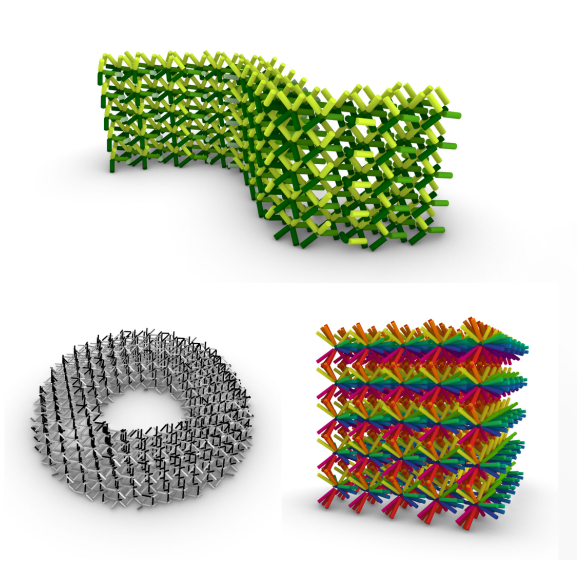


Figure 5: Ghazal Javidan Results. Source: (Javidan / Author 2021)

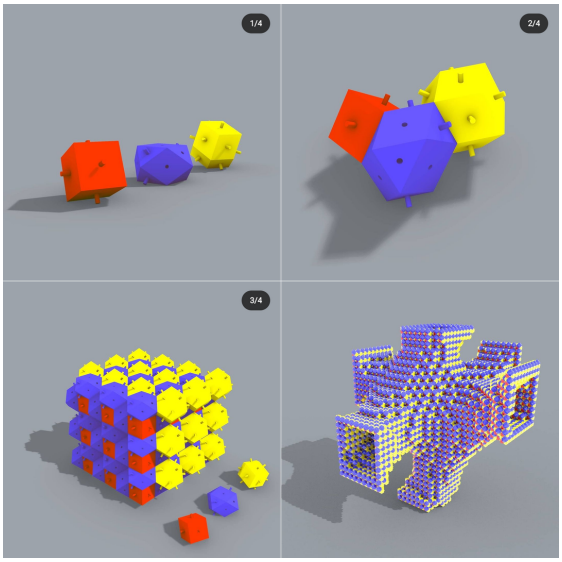


Figure 6: Kevin Flores Results. Source: (Flores / Author 2021)

3.2. Fabrication workshop results

The revised output of the Fabrication Workshop was a self-supporting construction of maximum dimensions ≈ 3' x 3' x 3'-6" springing from a triangular base of only ≈ 12" per edge (Figure 8).

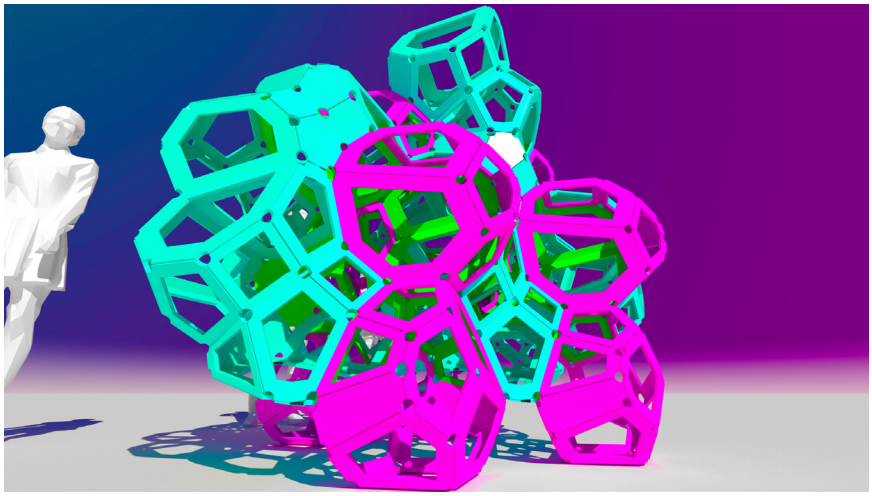


Figure 7: Original Installation Design. Source: (Author 2021)

The original Fabrication Workshop would have presented an opportunity to explore the fabrication of Space Group assemblies at architectural scale. There is an ongoing need to fabricate all types and scales of these aggregations to test their utility in real-world construction. Of particular importance is prototyping of best practices in removing or

retaining edges or faces, which is handled differently by the original (Figure 7) and realized (Figure 8) designs in instructive ways. The predetermined design of the original Fabrication Workshop proposal was optimized for material efficiency through the removal of redundant internal faces. Th top-down nature of this design would have required participants to closely follow the original design, removing participant agency and relying on them primarily a source of labor.

Similarly, with each face having a limited number of possible correct locations in the sub-unit honeycomb, face orientation, marking, and sorting would have become non-trivial tasks, significantly increasing both the space and hierarchy of roles needed for organization and assembly.



Figure 8: Final Installation. Source: (Author 2021)

The systems of discrete sub-units created by Horta results in what one participant described as a "puzzle with no wrong answers."[10] The smaller more modular construction retained the faces culled as redundant in the original design method, becoming a set of seven parts, as described in Table 2. This simplification allowed for a collaborative, open-ended, reconfigurable design methodology which preserved participant agency. The extra space and organizational hierarchy necessary in the predesigned honeycomb above were rendered moot. The “kit of parts” approach meant that participants did not need any background in the Space Groups, [Software 1], or the details of a project sequence to participate fully. The ad-hoc community which gathered to build the Installation became active collaborators in the final design. Notably, participant Ulysses Hermosillo, brought his 12-year-old son, who quickly became the official placement specialist. Ulysses’s son would loosely attach completed sub-units to the existing aggregation to heuristically prototype stability and aesthetics. As the construction grew, the group designed together by discussing these placements. Once consensus was reached, [Participant 4] would fully attach each sub-unit. (Figure 9)

In the original Installation the assembly was to follow an algorithmic process to create a predetermined final form. Every aspect including assembly order had to have some measure of pre-planning. In contrast, in the revised design the form was the result of community decision-making and emerged from the application of a heuristic, observation-based analysis of the material factors of stability and balance. This piece joins a legacy of projects in which a computational construction methodology forms a deliberate structure of the community of participants. This includes structures throughout history - from the Agnicayana Altar (Staal 1999:105-127), through typologies such as Amish Barn Raisings and the Slinningsbålet pyres, to the work of architects in the more recent Discrete tendency such as AUAR. (Bartlett 2020)

As a three-day workshop, the outcome was more limited in scope and aim than any of these precedents. But it shares the important characteristic: the application of computational processes to simplify decision-making can allow participants to focus on building the communal and social aspects of the project. By practicing the common cause of construction the creation and maintenance of the social bonds which facilitate it, the participants’ roles as individuals within a community are also shaped. (Bell 1992:. 76, 125. Staal 1999: 105-127) The flattening of hierarchy - afforded by the design method being heuristic rather than algorithmic - allowed the participants to discover what the form would become together as equals.

Initially the revision of the workshop format and the changes in scope that necessitated could have been viewed as a setback. In keeping with the theme of *Architecture Into The Unknown*, scrapping the original files and workflows became an unexpected opportunity. What emerged from the last-minute improvisation became an opportunity to explore the human dimensions of this design and construction method.

CONCLUSION

Originally intended to accelerate machine assembly, the process described above also has the unexpected outcome of facilitating collaborative human fabrication. The system is fit for both purposes not through affording a maximum number of slightly different possibilities, but through providing fewer and better-defined ones. Much of the hierarchy required for an algorithmic approach is negated by the heuristic method. But the constant negotiation and sometimes indecision required to undertake a heuristic process is negated by the kit of parts approach. While there is no way to deny that implementing an algorithm is more "efficient" for realizing projects of more significant scale, applying a heuristic method to smaller scale projects such as this allows for increased participant agency and the creation of a community through the shared effort.

The realized Fabrication Workshop echoes the theme of *Architecture Into The Unknown* because methods previously unexplored in CORAL were implemented, and consequences of using the Space Groups to construct a kit of parts for collaborative assembly became known. The results of the workshop opened a new avenue of scholarship for the author. The examination of the application of computational methods in community construction through history – arrayed across a continuum from purely algorithmic to purely heuristic – has resulted in further development of this line of inquiry. Although the project began from the roadmap for CORAL to implement algorithmic techniques in conjunction with advanced fabrication methods to realize an accelerated automated modular assembly workflow, a surprise result was encountered – related methods facilitate an unexpected social outcome. The system's heuristic qualities afford a faster construction process requiring less and organization, allowing the participants to focus on learning to work together as a community.

The resonance between human and "machine" methods in this project belongs to a lineage of community construction reaching back thousands of years. Yet it is also very timely. As computational designers continue to seek applications for our technologies which address the urgencies of our unknown societal and planetary futures, the results of this Fabrication Workshop are a useful (if small) example. Significantly, the exercise revealed that this approach to design and computation can open participation in advanced fabrication projects to those typically excluded by the amount of specific disciplinary knowledge typically required – even a child. It is hoped that this can serve as an example to others to consider the social potential of what we may have previously thought of as primarily a machine process.



Figure 9: Final Construction Method – Heuristic Community Participation. Source:(Author 2021)

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ENDNOTES

1 The name given by the author to the individual geometries generated by Horta.

2 One can see this increase in formal complexity from the greater integration of computerized design tools from the completion of Eisenman Architects' Wexner Center for the Arts (1992) and Aronoff Center for Design and Art (1996).

3 This also facilitates the planned use of Machine Learning and similar methods.

4 In cases (such as this) where the generator points fall at Special Points, the result is also isomorphic to $I6\acute{1}1$ and $I321$.

5 This Position causes $I6_31$ to differ from $I6\acute{1}1$ and $I321$ in symmetry operations while maintaining all of the other shared characteristics.

6 An evenly distributed lattice contains two times as many sub-unit R as sub-unit Q. For the Workshop an equal number of Q' and R' sub-units were produced to simplify laser cutting and to drive variation.

7 For example, if the $I321$ pattern were the base case, a move as described would cause a maximum of (2) morphologically distinct units.

8 Goal-oriented and evolutionary methods were not examined.

9 This participant has also continued to use Horta in other interesting digital workflows since the Workshop.

10 An observation made verbally during the construction process.

Low Tech Strategies with High Tech Tools: Integrated Modeling in the Early Architectural Education

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ABSTRACT: There is a widespread appeal to foster the adoption of building performance simulation (BPS) tools in the education of aspiring architects with the goal of commonplace integration in architectural practices worldwide. This adoption enhances an architect's working methodology through new forms of observational testing, which demonstrate how architectural boundaries and environmental states interact. Given the opportunities provided, students should exercise careful consideration when incorporating BPS tools into their architectural workflow. This paper presents years of BPS tool implementation in the early stages of architectural education and how this work addresses new user challenges, such as the superficial acceptance of BPS outcomes, a corresponding assumption that BPS tools predict building behavior with absolute certainty, and the subsequent abbreviation of the design process when quantifiable BPS results fall within a desired set range. This paper presents a unique approach that prioritizes low-fidelity BPS tools in iterative, multi-scalar, and interactive ways that embrace the replication, augmentation, and even contradiction inherent within architectural design workflows. Instead of settling on the narrowly deterministic solutions generated by BPS tools, students exercise the potential of these state-of-the-art platforms in a manifold way, using them to observe the rich interactions between articulated architectural boundaries and the environmental states they help shape. Fourth-year students in an undergraduate architecture studio practicum use numerous low-fidelity BPS programs to observe how a building can be tasked to produce system-integrated outcomes that satisfy benchmarks set by the 2030 challenge.

KEYWORDS: building performance simulation, low-fidelity design tools, non-expert simulationists, passive low-energy architecture

1.0 INTRODUCTION

1.1 Integrated design with BPS

In 2020, the National Architectural Accrediting Board (NAAB) revised its conditions for accredited architecture programs in the United States to embrace criteria related to systems integration that grew out of initiatives in the architectural practice to deliver higher performing, environmentally conscientious buildings (NAAB 2022). The driving force behind these changes is widely acknowledged within architectural and allied disciplines: the need to design better long-term operational buildings with fewer energy-intensive resources (Patrick and Charles 2009). A crucial component in this added emphasis on building integration is using low-fidelity BPS tools in the design process that continually provide observable performance feedback that students use to inform early design decision-making.

Technological advances in recent decades have made performance observation tools evermore accessible to simulation non-specialists who have progressively incorporated BPS platforms into their architectural design workflows (Soebarto et al. 2015). To fulfill the promise of a BPS-enhanced architectural design practice, educators should set the foundation for its responsible use in the early stages of an architect's education. The notion prevails that the earlier one introduces architects to BPS toolsets, the more influential the implementation will be once those students become practitioners (Hopfe et al. 2017). However, when introducing specialized simulation tools within a generalist architectural design curriculum, educators should exercise caution with students initially classified as consumers or performers of these sophisticated toolsets (Alsaadani and De Souza 2019). The introduction of advanced tools to increasingly inexperienced user groups demands the question of how should the modality and sequence of BPS tool instruction be carefully calibrated to not overwhelm new users with high-fidelity platforms that necessitate steep learning curves while instilling levels of accountability when using low fidelity tools more appropriate for a generalist user group like beginning architecture students?

To fully address this question, the work undertaken herein asserts that a practicum model of BPS training is essential as it encourages students to perceive firsthand the impact of BPS processes in the early stages of schematic design instead of using these tools in the later stages of design development to merely post-rationalize an already developed building. Adopting BPS in the architectural design studio provides students with critical insights that connect a building's disposition to a specific set of performance aspirations derived from established guidance. With this capability, BPS tools enable students to convert their hopeful optimism about how they want the building to behave into demonstrable evidence about how the configured building satisfies these objectives.

1.2 BPS in the early design process

Central to this new capability is the observation of architectural boundary and spatial state relationships early in the design process. A student is empowered when they can systematically test how changes to boundary configurations produce different environmental states within a building over time. Insights such as these lead to innovations in

building design tailored to the specificity of use and environment that are unique to each project. In this sense, designers can artfully design the performance of the building before deterministically engineering it. This approach steers students through the basic tiers of environmental design in which the basic building design and passive design strategies are prioritized up front, encouraging architects to find the appropriate spatial disposition and articulation of boundaries relative to the dictates of extensive climate regimes. The third tier would consist of mechanically engineered systems that would supplement the essential building and passive design strategies formulated by the architect beforehand (Lechner 2009). Instead of students developing architectural schemes based on their look alone, they use BPS tools to incorporate new data sets that test building ideas relative to pervading environmental phenomena in model domains. A model domain encompasses three primary constituents: the geometric and material boundaries representing the enclosing elements of the space under investigation; the prevailing environmental input states such as fluid air, radiant heat, or visible light; and the subsequent mathematical calculations between environment and boundary recorded as state change within the domain volume (Herman 2010). This process creates observable outputs of complex physical interactions for students to learn from and respond to critically.

A BPS-enhanced architectural design process orients students to first-principles relationships, the most fundamental issues in exercises that seek to artfully shelter inhabitants from extreme climate conditions. Through empirical study, students can follow in the footsteps of their pre-industrial predecessors to test fundamental ideas that intertwine the use of available resources to achieve the necessary levels of acclimatization needed for shelter. Balancing up-front resource expenditures against long-term operational savings is a recognized contribution made by BPS integration in the early stages of the building design process (Hensen and Lamberts 2011). While our predecessors optimized the built environment out of necessity due to limited mechanical advantage, we must, through self-regulation, enhance the material and energy resources allocated to the functioning of buildings by leveraging our 21st-century technological gain through virtual trial and error testing capabilities.

For early builders, trial and error knowledge was presumably acquired over centuries of construction. However, for BPS early adopters today, trial and error knowledge can be acquired in days to help formulate a building concept that underpins the fundamentals of bioclimatic design. These short-term demonstrations of building behavior significantly impact how architects are educated today. During the conceptual stages of a project's development, real-time observation of building massing, orientation, and aperture placement alternatives incorporates acclimatization and energy into the design language instead of principles to be engineered during later stages of project development. This approach situates the primary goals for a BPS methodology, which treats environmental factors as a medium of the building arts by highlighting components that are more about informing and orienting lines of inquiry and less about problem-solving. This practice elevates activities commonplace during schematic building design phases, such as replication, contradiction, and augmentation, while making them integral parts of the BPS testing process. These procedures partner appropriately with its generalist user group by focusing on the integration of physical building systems as the basis for conceptual design while sidestepping attempts to use low-fidelity BPS tools to predict the future behavior of real-world building performance deterministically.

1.3 Low-fidelity tools for the non-specialist

While recent advancements have brought user-friendly simulation interfaces to market for non-specialist adoption, these tools can be a 'black box' for new users who struggle to fully comprehend how computational models impact how user inputs are calculated within a domain system, especially when using low-fidelity tools (Augenbroe 2003). The difference between low and high-fidelity BPS tools can be notable. Low-fidelity tools provide an inviting entry point for new users but do so at the expense of limited input parameters and computing bandwidth. Alternatively, high-fidelity tools offer increased computing power at the cost of steep learning curves that stem from complex domain configurations. This credibility gap between the two BPS tool categories should be acknowledged when introducing new users to various tool options (Beausoleil-Morrison 2019). User-friendly platforms lack the accuracy and reliability of their expert analytic companions, especially when testing the viability of passive low-energy design strategies such as natural ventilation cooling and thermal heating. Using low-fidelity BPS tool types holds excellent value when the non-expert user is mindful of the simplifications and abstractions built into the domain calculations being produced. Without this understanding, generalist users like architects risk misinterpreting the results produced in a domain, responding with boundary configurations that produce unintended effects (Reinhart et al. 2012). The ability to navigate new user-friendly interfaces that focus on the impacts of technologically enhanced boundaries and on-site energy production integration can be a significant skill set when using low-fidelity BPS tools to explore essential building and passive design strategies.

The defined impediments can become more pronounced when introducing low-fidelity BPS tools to undergraduate architecture students, considering that their knowledge of the art of building itself is still in the formative stages. Undergraduate architecture students should operate laterally in architecture, acquiring a comprehensive knowledge base while honing their practical skills in integrating and synthesizing this knowledge toward the building craft. Regardless of the user-friendliness of an interface, introducing state-of-the-art performance modeling tools in the early stages of the architectural education should be undertaken with pedagogical methods appropriate for its user group in the context of a larger curriculum track. Students should be taught these tools to their level, with their knowledge and interest levels in mind, while not being overwhelmed by the depths of this emerging BPS field (Frank 2015). Beginning BPS users should be acclimated to tool usage, beginning with tool instruction and demonstration followed by stages of tool application within practicum course types. Empowering students with control over BPS tool usage earlier in the educational track, especially after overcoming challenges related to tool operation, instills a necessary level of skepticism. This approach helps avoid accepting simulation results at face value and encourages using the tools to steer lines of inquiry rather than considering design questions answered through a BPS solution.

This paper, therefore, offers and discusses a unique approach to teaching BPS tools in the undergraduate program of architectural study in which students, acting as both consumers and performers of low-fidelity simulation programs, cultivate a manifold application of testing routines that orient open-ended lines of design inquiry. This pedagogical approach utilizes a heuristic process to overcome limitations in low-fidelity tool exactitude and complement the recursivity of a robust schematic design investigation. It encourages the open-ended exploration of empirical knowledge by promoting the development of new study threads from feedback obtained in earlier stages. By installing BPS tools within trial-and-error cycles, students not only have the opportunity to test out spatial boundary alternatives but can also systematically evaluate the limitations of the tool in use. This opportunity is particularly evident when running multi-domain simulation routines that expand the range of testing, utilizing the branch of one domain to confirm and refute the reliability of another. Paralleling these exploratory sequences, an online repository of learning tutorials breaks down software instruction, freeing up time during the practicum to explore tool capabilities through hands-on application. Framing these exercises allows non-expert users to find value in BPS tools within a non-specialized work environment. This approach relieves them of theoretical grounding, mathematical calculations of physical behavior, and solver algorithms more appropriate for expert users aiming to contribute to a specialized field.

2.0 METHODOLOGY

2.1 Process constituents

Design integration using low-fidelity BPS tools in an undergraduate architecture studio occurs in four primary phases: the geometric modeling of domain boundaries, defining key input states, multi-domain simulation, and output corroboration that directs stages of integrative study at different scales. Numerous parameters that guided the selection of digital tools were identified in support of this methodology. These parameters consisted of BPS software platforms that allowed architecture students to interact with programs using graphic or visual indicators, also known as graphic user interfaces (GUI); programs that related architectural boundaries to environmental states in an intuitive way; and software that supported the reiteration of architectural boundary configurations, material assignments, and shifts in investigative scales. It became clear that students would benefit from using low-fidelity simulation tools whose functions focus on simplicity and reiteration over real-world precision and complexity. The base geometric modeling platform used to carry out the testing is McNeel® Rhinoceros™, whose domain range functionality is expanded with the tethering of companion BPS programs such as Climate Consultant 6.0, cove.tool, and ClimateStudio. McNeel® Rhinoceros™ is a NURBS (non-uniform rational B-spline) based geometric modeling program developed by Robert McNeel & Associates preferred for its capabilities in abstracting geometric models and for its interoperability, which allows BPS tools to be used within the modeling domain and for geometry to be exported for use within web-based BPS applications. Based on the work of Baruch Givoni and Milne Murray developed within the University of California System, Climate Consultant translates annual 8760-hour weather data into graphic displays while offering passive design strategy recommendations in response to climate datasets through links to 2030 palette guidelines. For architecture students, this program provides the graphic visualization of region-specific climate patterns while aiding in developing building performance aspirations in direct response to extensive environmental parameters. Cove.tool is a web-based environmental analysis tool developed by a team led by Sandeep Ahuja, Daniel, and Patrick Chopson. Its user-friendly interface and wide-ranging multi-state analysis options make it a preferred choice. The platform's ease of use allows students to observe how basic building boundary configurations perform, accounting for myriad environmental factors such as daylight, solar radiation, views, comfort, envelope configuration, systems integration, water management, and carbon footprint. ClimateStudio was developed at the Harvard Graduate School of Design under the leadership of Christoph Reinhart and is a daylighting, solar radiation, and visual comfort analysis tool that plugs into the Rhinoceros™ modeling platform.

2.2. Tool sensitivity

Overall, the toolkit used in the undergraduate studio setting conforms to accessibility requirements for burgeoning user groups, including complimentary educational access, compatibility with standard modeling platforms, and a user-friendly interface. However, with initial adoption, students begin to sense the limitations of tools geared toward non-expert user groups. During trial periods, as students conduct informal sensitivity tests on user-friendly BPS tools, they encounter inconsistencies regarding real-world fidelity, especially when incorporating first-principles passive design strategies into exploratory routines. For example, when students' input parameters change into a low-fidelity BPS domain to account for factors such as natural ventilation, the resultant performance impact reported by the system contradicts practical wisdom, going against the grain of established passive low-energy architecture recommendations from building performance experts. We recognize the challenges in modeling complex measures such as natural ventilation with an operationally straightforward BPS tool but also note that low-fidelity tool limitations bring about an understandable uncertainty about the reliability of the results produced from the new user's perspective.

We present a sample scenario to provide additional context about undergraduate students' challenges when operating user-friendly BPS tools. This scenario illustrates an intuitive sensitivity test, reflecting new users' encounters while iteratively analyzing a building prototype reconfigured to align with 2030 palette resource recommendations. This illustrative example begins with a linear building oriented perpendicular to the prevailing wind direction. A large sweeping parasol roof and elevated ground planes fully enclose this baseline configuration. When a user-friendly tool runs a BPS analysis of this configuration, it reports the resulting energy use intensity (EUI) at 31.84 Btu/sq.ft./yr (Figure 1A). Introducing boundary reconfigurations to constrict wind flows, which increases cross-ventilation velocities through a central opening in the linear building mass, results in an EUI value of 33.91

Btu/sq.ft./yr (Figure 1B). This energy use increases conflicts with environmental design guidelines recommending cross ventilation and intermediary space development as viable design strategies that offset energy use.

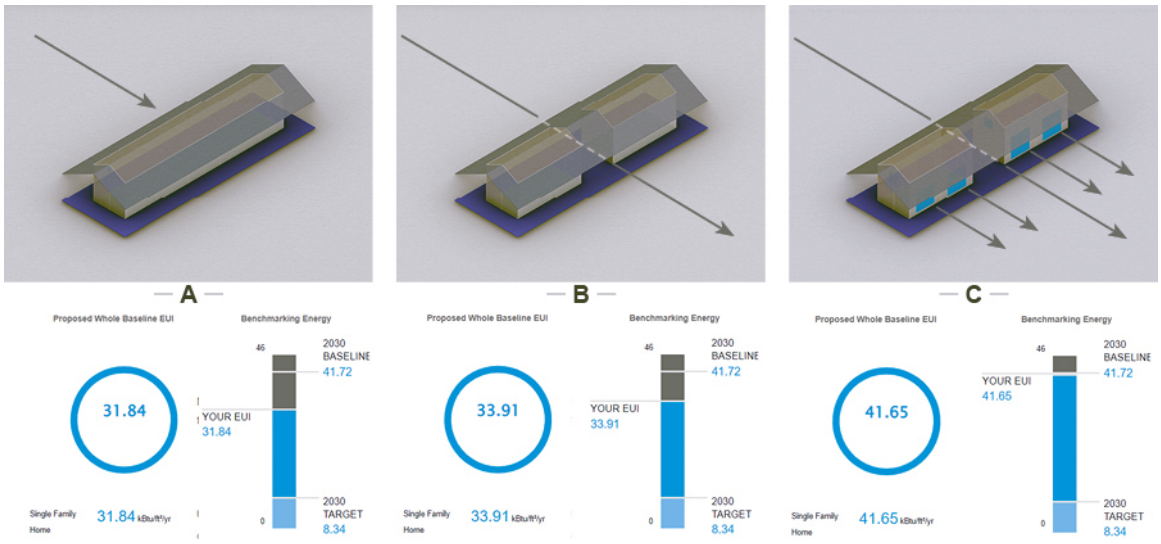


Figure 1: Sensitivity testing of natural cross-ventilation strategies. Source: (Frank 2023)

Furthermore, reconfiguring boundaries a third time to include opposing operable windows in enclosed areas aligned with the prevailing wind direction significantly increases the EUI value to 41.65 Btu/sq.ft./yr (Figure 1C). This increase in energy use again conflicts with a sustainable design framework that encourages aperture operability to permit prevailing breezes to cool enclosed indoor space types. In this case, varying the boundary input parameter while keeping the other parameters unchanged results in simulation output that contradicts the established guidance about passive design strategies. This scenario highlights the need for new user scrutiny when using low-fidelity BPS tools. While operating outside hermetically sealed boundary conditions, this example highlights domain sensitivity. Students should receive a BPS methodology that acknowledges and overcomes tool limitations.

2.3. Process overview

Owing to the steep hurdles present when incorporating low-fidelity BPS tools in early architectural education, the innate inclination for a new user would be to abandon the value added by these applications because of their apparent shortcomings. However, this paper offers an alternative methodology that prolongs the commitment to user-friendly BPS platforms for non-specialist users and eases using these tools in the beginning phases of the architectural education. This process consists of three main components: reciprocity protocols, concurrent multi-parameter decision-making, and result corroboration that work in unison to surmount shortfalls in tool reliability by exploiting the augmentation, contradiction, and replication latent in BPS protocols yet explicit in phases of design inquiry. In this sense, BPS tools are considered sketching implements by the architect, used to try out new ideas and orient already established lines of inquiry. They contribute to the essential tool kit that constitutes an architect's workspace, adding new implements that can draw comparisons and distinctions from within the integrated system of exploration to help chart the trajectory of speculation germane to a project's schematic development. Instead of using BPS tools to answer questions, effectively abbreviating a design process, these state-of-the-art programs contribute to the open design system, expanding upon preexisting branches of study, adding new pieces to the puzzle as an active contributor to design integration, not as a reductive solver of problems.

3.0 INTEGRATED DESIGN STUDIO

3.1. Studio vignettes

An undergraduate architecture studio sets the BPS methodology, where project-based briefs exercise integrated design principles prioritized by accrediting bodies. BPS tools are integral to this course as they provide observable and measurable feedback documenting the performative aspects of design schemes, one of the primary goals of the studio course that underpins building integration. While providing a soft introduction to BPS tools in a lecture format that maps principles of environmental technology to the analytical potential of simulation platforms, the studio offers a designer-centered approach. In this studio, students can simultaneously exercise the performance tools and consider the environmental aspects of building design. BPS tool instruction occurs through an online learning platform that hosts web tutorials for students to watch outside the studio meeting time. Breaking out the tutorials from the studio setting allocates additional time during the studio period for testing design schemes earlier in the process due to the dual threads of instruction. The following outcomes highlight how BPS tools have been used in recent studios as students pursue aspirational goals related to design integration using essential building elements and passive design strategies.

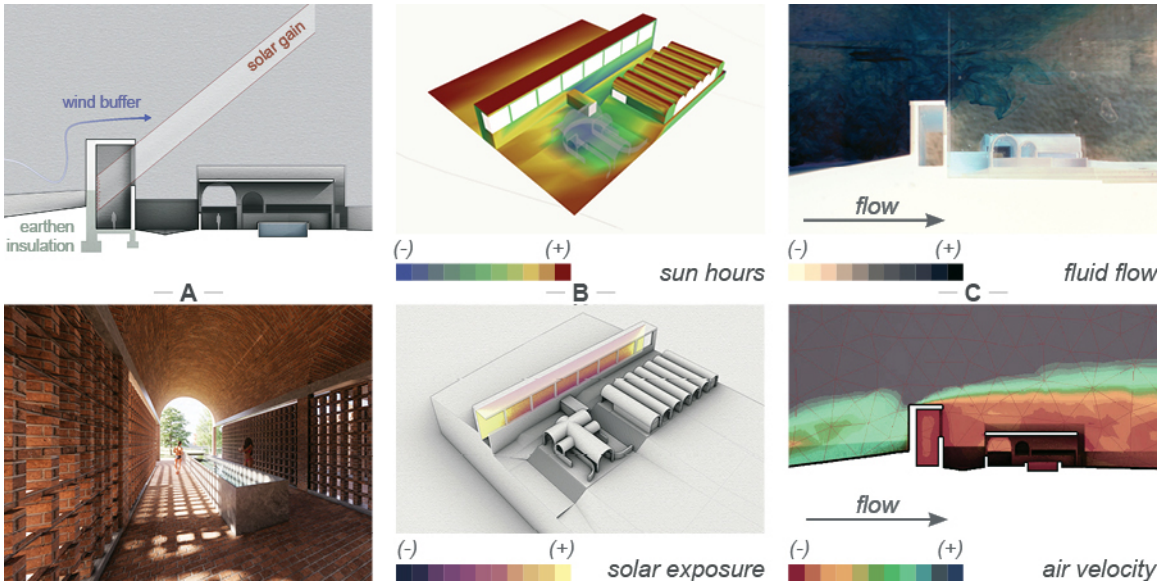


Figure 2: Vignette 1 demonstrating the use of reciprocity testing protocols. Source: (after Sweat 2023)

3.2. Vignette 1: reciopricity protocols

BPS-enhanced integrated design studios commonly formulate site and program constraints with a demand for enclosure alternatives. In these alternatives, students utilize architectural boundary conditions to heat, cool, ventilate, and light inhabitable spaces with minimal high-grade energy sources. In this first student example, Greg Sweat designs a thermal bath set in an alpine region in the northern hemisphere where heating demand far outweighs the need for cooling. This project sets a circulatory system along the site's windward side, which serves and protects jewel-like program volumes along the site's solar-infused southern edge (Figure 2A). The central performance aspirations that dictate this configuration include the creation of earthen buffers to protect from cold northerly winds, making a series of rarified rooms that benefit from solar exposure, and resulting heterogeneous spatial zones that users can migrate their activities to and from. With assistance from experienced staff members, Greg uses progressive path-tracing simulation engines to study how wind-protected spaces could express varying degrees of solar exposure. He also utilizes fluid dynamics testing to study how supplementary building masses engaged with the earth can shelter primary program spaces from the wind. With encouragement from faculty, Greg employs reciprocity protocols to calibrate the results from three analysis types: applied research, physical prototyping, and digital simulation. Aiming to confirm how the configuration of architectural boundaries shapes environmental states with or without mechanical means, this approach utilizes three different datasets to make critical comparisons. Conducting reciprocal analysis with each state type, Greg uses 2030 Palette recommendations for wind buffering, physical prototypes like water table testing, and computational fluid dynamics testing using digital platforms (Figure 2C). Used together, it helps him understand how his proposed architectural configurations can shape cold winter winds from the north. Similarly, different BPS platforms perform redundant testing of passive solar gains, where outcomes of annual solar exposure in one platform accompany sun-hours visualization from another to confirm recommendations made in the 2030 Palette (Figure 2B).

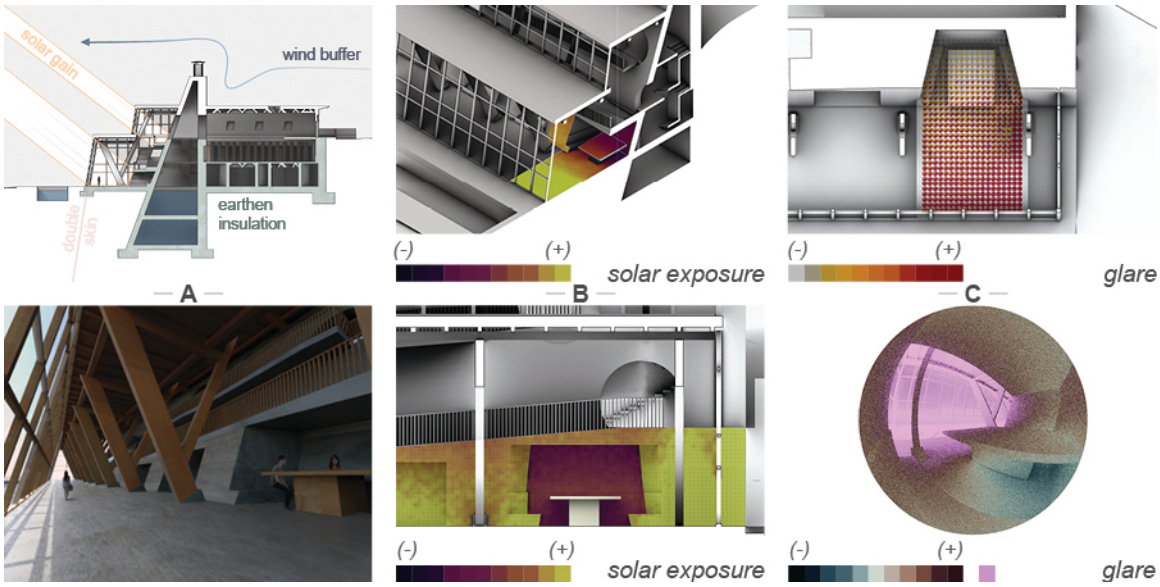


Figure 3: Vignette 2 demonstrating the use of concurrent multi-parameter design making. Source: (after Haller 2023)

3.3. Vignette 2: multi-parameter design making

In the second student example, we witness the potential of plug-in simulation programs to provide environmental feedback relative to the competing factors in space design. While the formulated site and program in this example are identical to the example above, we can see how the students navigated the repository, uniquely embracing a distinct set of principles toward creating aspirational goals. In this case, Evan Haller, compelled by the potential of solar heating, composes an elongated southwardly oriented sunspace. He defines it with expanses of glass on the sun side and incorporates a heavy wedge-shaped thermal storage device set into the earth (Figure 3A). Evan articulates this elongated sunspace through studies that examine the room's proportion, the transmittance of the glazing side of the room, and the solar absorption potential of the opposing mass surface containing degrees of inhabitation. Early in his process, during faculty consultation, he identifies conflicting desires that require a singular solution, namely the need for direct solar gains in spaces intended for visual comfort. On the one hand, Evan observes outcomes from multi-domain solar ray tracing tests to gauge the degree of radiant exposure on mass surfaces (Figure 3B). On the other hand, he observes the results from glare analysis in parallel to ascertain the visual impact of the sun entering the space for occupants (Figure 3C). In this example, concurrent multi-parameter decision-making accounts for many factors, including those with competing demands, such as human sensitivity in the context of direct solar gains. As we see here, the widening array of low-fidelity BPS tools can cycle through numerous analysis types to assess the competing needs that play out in space synchronously, facilitating the design of occupant well-being and building operational efficiency in concert.

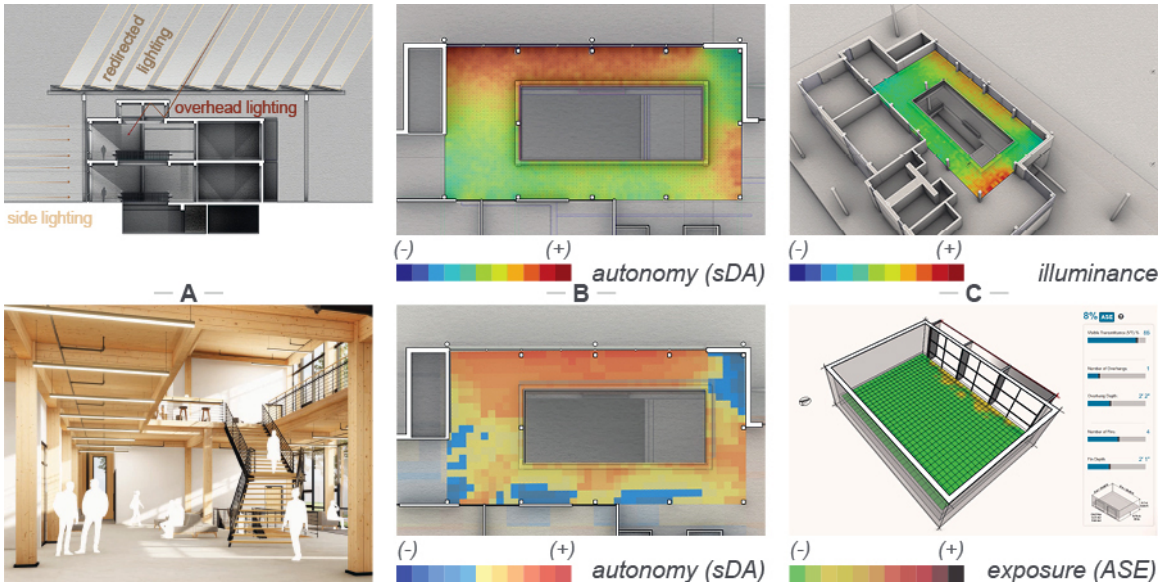


Figure 4: Vignette 3 demonstrating the use of result corroboration. Source: (after Jerabek 2022)

3.4. Vignette 3: result corroboration

Unlike the two vignettes above, the third integrated studio vignette proposes an ecological learning center in a warm-humid temperate climate on a college campus. The student in this example, Anton Jerabek, formulates early interest in a series of impromptu study spaces around a central two-story atrium. Pursuant to his interest, he studies the quantity and quality of natural light through a series of daylight studies of the circulation areas that circumscribe the common two-story space. Because the project is located in a climate where solar heating is a concern during the summer months, Anton incorporates strategies of reflected daylight to avoid overheating interior spaces, following recommendations from the Climate Consultant. During these studies of shading partnered with indirect lighting, Anton develops highly permeable spatial boundaries that keep unwanted heat gain out of inhabitable spaces while welcoming an abundance of indirect lighting. He achieves this by sourcing reflected daylight from numerous directions, aiming for achievable uniformity and illuminance along visually sensitive work planes (Figure 4A). Using a web-based low-fidelity simulation platform, he conducts quick, physically based light simulations to size and orient apertures and configures interior surfaces to receive and redirect daylight. These findings can be compared to additional studies run using a companion lighting simulation platform housed inside the base modeling domain to ascertain a more granular understanding of daylight behavior relative to the reflective surfaces encompassing Anton's proposed atrium work area (Figure 4B). In this example, result corroboration encourages Anton to challenge the acceptance of analysis results at face value, using multiple simulation threads to verify initial tests run by low-resolution tools. The redundancy provided by a multi-domain process also allows him to see different results from within the same platform, where one branch focuses on light distributions in a single floor plane while another looks at envelope configuration in sourcing and redirecting light (Figure 4C).

CONCLUSION

The work illustrates the recent incorporation of low-fidelity BPS within an undergraduate architectural design studio. These exercises aim to encourage the early use of BPS tools in architectural workflows for critical adoption, encouraging aspiring architects to examine how these tools offer new insights into how building boundaries impact the environmental states around them. The observable feedback of boundary-state relationships provided by BPS tools establishes new ways for architects to incorporate sustainable concepts into their daily working methodologies. We find an increased awareness of environmental design principles in the vignettes above. Instead of designing

intractable forms in a vacuum, students make a concerted effort to organize space around the dictates of climate because they can see firsthand the impacts of early design decisions. This approach also prioritizes a process that attunes itself, inducing one analysis domain branch to reinforce or critically examine the relative reliability of another. Instead of relying solely upon inaccessible high-fidelity simulation engines to validate results, the non-expert architect can compare the output from within the integrated system of accessible tools, both physical and digital, toward the development of conscientious and sustainable building outcomes. Expanding upon traditional architectural media, we find students benefiting from the reiterative sequences offered by many low-fidelity BPS analytical tools today, especially in support of equally redundant, contradictory, and complimentary processes.

These tools support an integrated process, where the linkages between different building system constituents must be known to craft a polyvalent yet holistic outcome. While incorporating BPS tools within the undergraduate architectural education remains nascent, its potential for embedding aspirational performance goals into the physical configuration of acclimatizing spatial boundaries is significant. However, challenges and subsequent improvements in the initial adoption remain for aspiring architects, inspired architecture faculty, and building performance modeling developers as we collectively improve how young architects see the environmental impacts of their early design decisions. Areas needing future work include the continued improvement of pedagogical exercises prioritizing the artful use of BPS tools in design studios. These exercises should open lines of inquiry instead of closing them down with deterministic solutions. Additionally, there is a need for scaffolding self-guided approaches to BPS usage in a studio setting that escapes a one-size-fits-all mentality, enabling creative user groups to formulate innovative practices. Lastly, we must identify new ways to highlight synergies in multi-state BPS workflows, especially when seeking polyvalent outcomes. Taken together, these improvements will help architects clarify their vision of building design by better integrating human, environmental, and material factors toward the making of coherent buildings, maximizing the contribution of each component within a unified system. As such, this coherent vision may result in poetic spaces that inspire inhabitants as much as they improve upon capital and operational resource consumption. It is about making something definitively new, encouraging architects to incorporate BPS in creating artful spaces, and strengthening expressed intentionality through these state-of-the-art tools. The next steps in this BPS work should focus on the integration, synthesis, and coherence of extensive constituents such as light, heat, and air, as the presence of a building intensively shapes them. These steps include the development of studio exercises that continue to subvert the standard application of BPS as a distinct stage within the schematic design process; the development of new standards of BPS output evaluation that highlights the range and relativity of results instead of quantitative absolutions perceived as definitive; and the formulation of novel ways to post-process BPS outcomes to see results in layered, integrated and synthetic ways.

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An Explorative Tracing Of Peer Learning Dynamics In A PBL-Oriented Design Engineering Education

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ABSTRACT: Facilitating deep, sustainable, and long-term learning is not a trivial matter. It is a core challenge in the educational processes aiming at sculpting the profiles of future designers with ability to take part in tackling the pluriverse crisis of climate, biological and social aspects we are facing as a collective. In this context, the paper aims to provide a rich situational insight into peer learning dynamics of a problem-based learning (PBL) architectural education in Aalborg at the Department of Architecture, Design and Media Technology (CREATE). We specifically focus on the concept of peer learning within design education that tackles design issues, which are typically referred to as 'wicked' matter of complex proportions that needs addressing on a cross-disciplinary level. Previous research discusses the processes of designing as both linear and situational combining the tasks of analysis, problem formulation, solution, and evaluation showing how working analytically and design-oriented at the same time remains a focal core of the educational process of training designers. However, working in smaller groups addressing wicked design problems introduces also matters of collaboration, decision-making and communication as important skill sets. To contribute insights, the main research question is the following: "How can the didactical practice of peer learning in groups in architectural education contribute to address wicked design problems? Furthermore, what are the potentials and challenges of group work in the process of design?" The paper outlines firstly the state-of-the-art and theoretical foundations. Secondly, empirical material from teaching at CREATE including firsthand insights into design processes is presented. Finally, the paper concludes with a critical discussion on the didactic potential of peer learning in a design education.

KEYWORDS: peer learning, architectural education, problem-based learning, tools for designing

INTRODUCTION

> The world itself becomes a place of study, a university that includes not just professional teachers and registered students, dragooned into their academic departments, but people everywhere, along with all the other creatures with which (or whom) we share our lives and the lands in which we – and they – live. In this university, whatever our discipline, we learn from those with whom (or which) we study. The geologist studies with rocks as well as professors; he learns from them, and they tell him things (Ingold 2013, 2).

The opening quote by emeritus professor of social anthropology at the University of Aberdeen Tim Ingold encompasses a generosity towards the environment that surrounds us all. A generosity characterized by the understanding that both human and non-human actors have something to offer in terms of learning – that all possesses agency. In the quote Ingold uses the rock as an example of material with which we learn and learn from. In the fields of Architecture and Urban Design, we study the design of buildings and urban environments. This caters for a multi-disciplinary focus with the designer performing on the one hand a creative and future-driven practice (asking what could be) and on the other hand a synthesis-oriented practice deeply rooted in an understanding of the problems at hand, that draws on various related disciplines such as landscape architecture, planning, architecture, engineering, sociology and geography.

Facilitating deep, sustainable, and long-term learning that sets candidates free to imagine other futures is not a trivial matter. It is a core challenge in the educational processes aiming at sculpting the profiles of future designers with ability to take part in tackling the pluriverse crisis of climate, biological and social aspects we are facing as a collective (Bjørn et al. 2023). Specifically, the architectural education at the department of Architecture, Design and Media Technology (CREATE) at Aalborg University involves group-based work and problem-based pedagogies as two central didactical pillars (Servant-Miklos 2020). This results in a learning environment with collaboration, communication, and responsible and robust learning strategies as the main vehicles for growth where peers play a central role.

In this contribution, we focus on the concept of peer learning within design education that tackles design issues, which are understood typically as a 'wicked' matter of complex proportions that needs addressing through cross-disciplinary competences. In this context, the paper aims to provide a rich situational insight into peer learning dynamics of a design-oriented education at CREATE based on problem-based learning didactics. To contribute insights, the main research question of this contribution is the following: "How can the didactical practice of peer learning in groups in architectural education contribute to address wicked design problems? Furthermore, what are the potentials and challenges of group work in the process of design?"

To this end, the paper offers rich empirical material on the design processes that takes place during group work at respectively the master's program of architecture and the bachelor's level of urban design at Aalborg University (AAU) collected during 2022. The material comprises questionnaires and qualitative interviews mixed with visual documentation of the different tools that are activated throughout the design process. The paper outlines firstly the state-of-the-art and theoretical foundations. In a second part, empirical material on the design processes as well as the usage of different tools for designing are presented. Finally, the paper concludes with a critical discussion on the didactic potential of peer learning in an architectural education in the context of the Aalborg model to support sustainable and deep learning and enable proposing design scenarios for a resilient future.

1.0 BACKGROUND AND THEORETICAL UNDERPINNING

1.1 Problem-based learning at Aalborg University

Specifically, and uniquely Aalborg University has a strong tradition working with problem-based pedagogies (Savin-Baden 2020) defined in the 'Aalborg model' with the pedagogical model 'problem-based learning' or PBL (Servant-Miklos 2020). PBL is anchored firmly within project-oriented group work where larger cohorts of students are placed into smaller groups of peers, with whom they collaborate closely throughout the course of a semester. The groups take responsibility for their own learning based on the defined learning requirements specified within the curriculum per semester directed at tackling society's current and relevant problems. This demands a high degree of self-direction and independent planning of tasks, which adheres to the ambition of educating independent critical professionals (Aalborg University 2015). The idea of "learning with problems" (Servant-Miklos 2020) thus demands skills and contentious self-direction in a peer learning setting in which students learn "with and from each other" (Falchikov 2003).

1.2 Peer learning approach

In architectural education previous pedagogic strategies were influenced by the idea of direct mentorships where knowledge seeps down from star architect to star prodigy (Steinø et al. 2012). This approach has been criticized due to its steered and directive character leaving only little space for independent innovations and since sought replaced by more dialogic-oriented pedagogies – peer learning being a central example of this that inserts dialogue instead of instruction (Nicol and Macfarlane-Dick 2006; Núñez-Andrés et al. 2022) and emphasizes analogic rather than canonic approaches to design (Steinø et al. 2012). A dialogic-oriented pedagogy entails learning taking place through interactions with peers driven by mutual curiosity rather than relations defined by fixed instructor and student roles and the underlying hierarchies to be found there.

Literature on peer learning specifically defines it as "students learning from and with each other" (Falchikov 2003, p. 3). The underlying idea stemming from dialogical pedagogy that emphasize the potentials of engaging students in open classroom dialogues that develop their mental capacities (Cui and Teo 2021). Peer learning may take place within the singular project group via discussions, meetings and the planning and division of tasks (in the following defined by the near-peer group) as well as between two groups on the same semester working with same project site and assignment or within a smaller segment of the semester's body of students or the entire semester body. It may even be facilitated across different semesters within the same education (Falchikov 2003). Existing literature on peer learning in groups characterizes it as widely self-organized which demands of the students being active and engaging in taking responsibility for their own learning trajectory with the aim of training critical reflection and stimulating self-confidence as a professional which enable the transferal of competences into a variety of situations.

The acknowledgement of the potential embedded within learning alongside and via student peers is widely described (see for instance Falchikov 2003; Cortright, Collins, and DiCarlo 2005; Hattie and Timperley 2007; Boud and Molloy 2013). One of the acknowledged outcomes of peer learning is the stimulation of student's ability to reflect and communicate their reflections in front of their peers – in that way rehearsing analytic skills (understanding what I am presented with) and their reflections on how something may be improved or adjusted (Pelsmakers et al. 2020; Núñez-Andrés et al. 2022). The latter requires abstract thinking that activates prior knowledge and encourages the transferal and application of that knowledge to the current situation and assignment at hand. By extension, the reflections stimulated by being presented with and reacting to the work of others, in several ways have the possibility to influence the student's own project development. This is referred to as a self-regulatory level with the possibility of adjusting behavior and ultimately affecting self-esteem as a learner (Nicol and Macfarlane-Dick 2006).

More critical points related to peer learning address issues of ensuring the relevance and quality of the provided feedback, discrepancy between the expectation and experience of a specific learning situation (e.g. a pin-up or supervision session), the required facilitation of a safe peer to peer environment, as well as the supervisor, educator or instructor automatically being regarded as the main authority by the students thus circumventing the purpose of inviting in other peers (Falchikov 2003; Turner 2021).

Essential for the peer learning situation is a sensitivity towards dialogue and reciprocal peer-peer learning (Pelsmakers et al. 2020) which demands particular attention towards the act of feedback. Constructive feedback is described by Hattie & Timperley (2007) as equally particular and context-specific asking questions such as: where am I going? (what are the goals?) – also called process of feed up; how am I going? (what progress is being made toward the goal?) – also called process of feedback, and where to next? (what activities need to be undertaken to make better progress?) – also called process of feed forward.

The good feedback practice is also discussed by Nicol & Macfarlane-Dick (2006), who outlines seven principles that foregrounds how feedback should have a clarifying character and stimulate reflection, while they also emphasize that feedback provides the instructors with new insights that are beneficial in shaping teaching activities onwards.

Hattie & Timperley stresses how feedback has no influence in a 'vacuum' but harbors agency if there is a known 'learning context' within which the feedback is situated (2007). They refer to this context as a continuum between instruction and feedback, which require a clearly stated purpose and description of the contextual setting for the peer learning and thus feedback situation, that secure alignment of expectations and a sense of clarity for all involved. In correspondence, several researchers point to the importance of recognizing that feedback is never only a one-way transmission of information but rather a situated and relational disciplinary practice (Carless et al. 2023). Instead, they argue we should rather prompt

> a view on feedback as an interactive process that unfolds through social encounters between course participants and resources (ibid., p. 1159).

1.3 Design processes and wicked problems

The drive towards finding a situated, sustainable and innovative solution to a specific design problem at a particular site, lies at the core of the education at AAU (Aalborg University 2015). Several researchers have engaged in discussing the process of designing. Donald Schön, Bryan Lawson, Nigel Cross and Mary-Ann Knudstrup and Ring Hansen are well known within the field (Schön 1968; Lawson 2006; Cross 2007; Knudstrup 2004; Hansen and Knudstrup 2005). The latter being the authors of the IDP model (Integrated Design Process) that is central for the PBL work which takes place at CREATE. Some processual models of design processes are almost linearly portrayed, albeit the underlying importance of iterations between phases of analysis, design and synthesis is emphasized (Hansen and Knudstrup 2005), while others are situational (bordering deconstructive) with tasks of analysis, problem formulation, solution and evaluation unfolding in parallel over time (Lawson 2006) underscoring the complexity of working analytically and design oriented at the same time. One of the central take-aways from these sources is however that design processes are both intuitive and iterative as well as informed by site specific factors. By extension, it is frequently emphasized (see also Williams, Ostwald, and Askland 2010) that the imaginative and creative process of form giving is something which is hard to describe and outline in a step-by-step guide. Doheim and Yusof (2020) even posits that students in design studios have different experiences than students inscribed in other 'theoretical courses'.

In this contribution, we specifically focus on the concept of peer learning within design education that tackles design issues, typically understood as a 'wicked' matter of complex proportions that needs addressing through cross-disciplinary competences. Buchanan referred to wicked problems as "a class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications of the whole system are thoroughly confusing" (Buchanan 1992, p.15). In summation, we offer the following characteristics of wicked design problems: they are open ended tasks that are hard to delimit (in scope and in time) and by extension are inherently complex - they are inclusive and generous in what they take into account. For instance, when it comes to stakeholders, designers practice within a complex landscape of end users made even more relevant by current debates on the troubles related to a strictly human-centric worldview. For designers to be able to suggest relevant design scenarios for robust futures they need to be able to make a site-specific attuned diagnosis and master various tools for visual communication (learning drawing formats, verbal communication, model-making skills etc.). Facing such wicked design problems that involve many uncertainties and unknowns leads to an elevated level of complexity during the design process. In this context, we specifically explored the potential and challenges of how peer learning dynamics could contribute to addressing these wicked design problems.

2.0 METHODOLOGY

The paper builds on empirical material on design processes that have been undertaken in group settings at the master's program of architecture and the bachelor's level of urban design at AAU during 2022 primarily and 2021, 2023. The subsequent paragraphs elaborate in turn on firstly the processes of designing through visual material gathered by the authors throughout the semesters (see section 2.1) followed by a section unfolding the role of being a peer through questionnaires and interviews with the involved students (see section 2.2).

2.1 The role of visual material in peer learning

The following series of images give an insight into the visual material and underlying collaborative processes used throughout the semesters related to the analysis, design explorations, evaluations as well as visualizations communicating design proposals. The series of images invite the reader into the ongoing process of proposing, debating, and evaluating designs.

Figure 1 and 2 illustrates how the visual material comprises both hand drawn sketches and map annotations from analysis investigations as well as design ponderings on manifold made with various markers and pencils supplemented by three-dimensional foam and wooden models investigating the form of singular buildings and adjoining building structures. The final column of images shows examples of final digital visualizations through axonometric and bird view perspectives.



Figure 1: Glimpses into the collection of visual material used throughout the process of proposing design solutions on building scale. From left to right illustrating respectively elements from the analysis (maps with annotations), hand-drawn sketches, model exploration on building scale and graphic renderings of final designs. Source: own material (Berger and Olsen 2024)

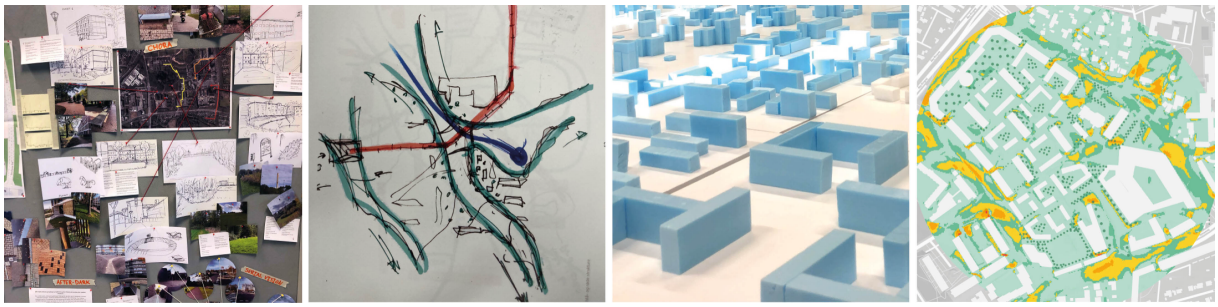


Figure 2: Glimpses into the collection of visual material used throughout the process of proposing design solutions on neighborhood scale. From left to right illustrating respectively elements from the analysis (maps with annotations), hand-drawn sketches, model exploration on neighborhood scale and microclimate analysis visualization of final design solution. Source: own material (Berger and Olsen 2024)

At AAU the groups make up the near-peer environment (typically formed in groups of five to six students) where they work closely together and perform tasks of analysis and problem definition, design explorations and final design decisions. Group work is undertaken in a range of different situations; much of it within the close environment of their near-peer group supplemented by weekly visits from their allocated main supervisor (instructor), who follows them from project start until end. Figure 3 contains a series of snapshots from the collaborative processes of developing design proposals in groups of near-peers. They illustrate how the processes of sketching on manifold material and via models is central for the project development and show how design experiments are developed in a mix of individual design explorations and small teams (of either two or three students) testing ideas before rejoining their near-peer group to discuss.



Figure 3: Glimpses into the process of developing design proposals in groups of peers. From left to right illustrating the mixture of individual, dual, threefold, and near-peer design collaborations that unfold between design peers. Source: own material (Berger and Olsen 2024)

Learning situations that differ from the everyday collaborations within the near-peer group and instructor are workshops, pin-ups and status seminars or midterm critiques. A workshop and a pin-up are typically organized in an open space with a flexible setup of pin-up boards and stools with the participation of the entire cohort of students on the same semester (or a smaller sample of them) including also representatives from the instructors. All able to and encouraged to offer feedback on the presented material. The analogue material on the pin-up boards is often hand-drawn material and the work models are equally sketchy. Whereas a workshop is scheduled over several consecutive days which are allocated for the students to intensively study and evaluate a certain aspect of their design within their near-peer group, a pin-up gives space in an hour-based format for an open collaborative discussion on the work in progress. A status seminar represents a format of a mid-term presentation that usually takes place in a closed seminar room with tables and chairs placed in fixed rows, where the groups use digital presentations with detailed illustrations, that give the impression of (more) final design proposals. As with pin-ups, the instructors and co-peers from the same semester can provide feedback in the situation.

Figure 4 illustrates a series of activities transitioning from learning situations within the near-peer group (left picture) towards evaluative discussions in pin-ups and status seminars with the participation of larger cohorts of students. The pin-up situation clearly foregrounded work-in progress through analogue material and sketches. Whereas in the status seminars digital presentations represented nearly final design proposals. Lines of sight and lines of speech differed greatly across these two situations, which draws attention to the importance of considering what kind of interaction any learning environment may afford. As Gänshirt points to how the materiality and the things with which you learn and discuss is extremely important – they become also contributing factors in a peer learning situation (Dunn 2014; Gänshirt 2020).

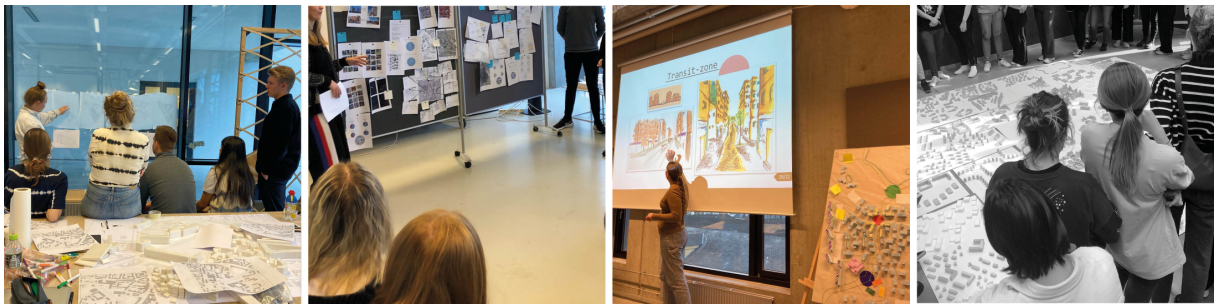


Figure 4: Glimpses into the formats of collectively discussing, debating, and evaluating design proposals as peers. Left to right transitioning from situations within the near-peer group towards evaluative discussions in pin-ups and status seminars with the participation of larger cohorts of students. Source: own material (Berger and Olsen 2024)

2.2 The role of being a peer

The included images of designing and evaluating serve to illustrate the learning situations which the students have been part of throughout the semesters. The following section 3 invites the reader into the experiences of the involved students with the aim of reaching a better understanding of the students' experience throughout the process of designing together as a collective. The paragraph builds on a questionnaire carried out with the students of the 7th semester architecture students (47 responses, 96% response rate) and four qualitative interviews with 5th semester bachelor students. Questionnaires and interviews helped to both qualitatively and quantitatively assess the students' perception and progression at different stages of the design process.

The questionnaire included 19 questions that covered topics related to course content, knowledge transfer, and overall assessment. The questions were posed in both open-ended quests as well as using a 5-point Likert scale (strongly disagree, disagree, okay, agree, strongly agree). The questionnaire was handed out to the students at the end of a workshop and pin-up. Students needed approximately ten minutes to finalize the questionnaire. The qualitative interviews where semi-structured inquiring into the respondent's experience during selected activities during the semester; study circles, pin-ups, workshops, and status seminars where the students were allocated an active role as peers for their co-students. In these situations, they reviewed and critiqued each other's design proposals through oral feedback in the situation, complemented by written feedback for which they were provided with peer feedback guides that outlined the important themes for the feedback. The interviews lasted for approximately one hour and the open structure allowed for the respondents to freely elaborate on their experiences during the semester.

3.0 DISCUSSION

Four interviews as well as questionnaire results supplied insights into the experience of being a student making a project and following the described activities. Each student volunteered different perspectives; both in terms of potentials and problems related to peer learning. In the following subsections, the main findings that illustrate the experience of peer learning dynamics in design education in the context of the Aalborg model are summarized.

3.1 Motivation and practices of peers in collaborative settings

> It was nice to be given an active role. And it was clear that you were supposed to say something. You felt obliged to be active. Others were counting on you (Excerpt from student interview, 2022).
>
> It kind of validates that you have your own voice. That your professional competences are not completely off (Excerpt from student interview, 2022).

The conducted semester activities and follow-up interviews with the students generally confirm that students gain motivation from being assigned the role as an active peer. One of the factors pointed to is the binding character of the assigned role; especially in the situation of a status seminar where peer-opponent groups were asked to be the first ones to offer feedback. Inactivity would have apparent consequences in the situation with the peer group receiving no feedback displaying the poor engagement of the opponent group, but the included quotes testify to the also affirmative motivation which the students experienced in that situation, which confirms the points raised in existing literature on peer learning.

The included Figures 1-3 however contribute also important aspects related to how the layout of the physical environment and the material available (sketches and models) in different ways support the peer feedback situation through either circular discussion formations where the hierarchy between participants is flat with the design material in the middle, rather than linear set-ups with the instructor as the center of attention and main contender. This confirms how feedback does not take place in a vacuum (Hattie and Timperley 2007) but that the particular material available and the layout of the rooms factors in. Students elaborate also that the insights they gain through

performing peer feedback rehearse their ability to offer relevant critical reflections, inquire into and understand different viewpoints which is necessary in tackling open-ended design problems with a multitude of end-users. Also, self-organization as well as discussion and working in collaborative environments prepares them for future work-related situations.

Also, one student offers the following explanation:

> You have an increased awareness towards the projects of others. You learn a lot seeing what others have done. And you take it back into your own project work (Excerpt student interview, 2022).

In confirmation the interviews contain passages with students offering insights into how peer feedback gives input that transfers and qualifies their own project work on the same semester and even beyond, as the positive experiences from collaborations on one semester inform future student practices in subsequent courses shaped around individual work where they independently continue to form smaller peer groups. This refers and confirms the notion that feedback supports students in an interactive and iterative design process (Carless et al. 2023).

3.2 From instructor to mediator

> There was a lot of focus on ensuring that the opponent groups were given space and time to talk. It could have been nice if there were a maximum amount of time. It is a shame if the opponent group spends all the time, that's kind of a waste of time. The supervisors did not have enough time. After we had noticed that too much time was spent on the opponent peer group, we adjusted our own line of questions – and narrowed it down to only three. Because they are not there to receive supervision for our sake (Excerpt from student interview, 2022).

A further aspect refers to the instructor's role in the peer learning dynamics, which the literature also addresses. On the one hand, the interviews pointed out that even though peer learning is central in the semester organization, instructors play an important role in guiding students in the various situations making clear what are we providing feedback for and how, thus structuring and framing the discussion and feedback settings among the groups. Especially in earlier bachelor semesters, the provision of key discussion points or basic guidelines helped students to understand and fulfill their role as an active peer in ways assuring that their feedback focused on relevant topics. Some of this may be achieved beforehand through guides and verbal direction. However, the students also point to how instructors have a critical role in the room as they perform situated on-site filtering and translating so to concentrate on key discussion points to avoid misleading peer guidance.

The included quote also reveals the student's inclination towards prioritizing the feedback from the instructor rather than their peer students. Some students expressed also, that without instructors filling a mediating role in peer discussions, it could become a de-motivating factor for some because students feel as though the quality of peer comments varies among the student cohort. The images in Figure 4 reveal also a dominating orientation (both visual and bodily) towards the position of the instructor in the given situation. These issues confirm the critical points raised earlier related to maintaining a certain quality of the peer-feedback (Falchikov 2003; Turner 2021). The instructor mediating the dialogue among student groups thus become central to provide a collective, supportive, safe, respectful, and appreciative environment among all involved. Otherwise, the collective setting runs the risk of creating tensions or demotivation among students.

3.3 From peer learning situation towards culture

> You measure and weigh your own project and others' based on a comparison with the rest of the semester's work (Excerpt from student interview, 2022).
>
> It [referring to the position of being assigned as peers across groups] is kind of forced out of us. We see it [referring to their project work] as kind of our little project, and it becomes insurmountable to get into someone else's project and process. That has been really isolated (Excerpt from student interview, 2022).

When it comes to peer learning, the students' reactions and comments relate in general points to how the prevailing culture of learning is short-term oriented, focusing mainly on semester deadlines and hand-in requirements. Also, it is clear how students' past experiences from earlier semesters and perhaps even before entering the university influences and affect how they conduct themselves in peer situations and in their overall learning strategies. By extension, it is not necessarily constructive to set up peer learning situations with room for reflection and intuitive discussions if the students have not yet learned to ask open and inquiring questions. In addition, if they have not previously experienced that offering inquiring reflections are well received, and that presenting rough and unfinished design suggestions may lead to unexpected yet valuable perspectives, it is difficult indeed to remain open for feedback through dialogue.

> We have become better at offering critique. And then you become better also at seeking out critique or feedback. There is a lot to gain by seeking out the other groups (Excerpt from student interview, 2022)

As the included quote also testifies, the students however also take note of how they have matured in their ability to invest in a shared learning community benefitting also their own long-term horizon of learning. The students independently offered insights into differently situations that they believed held peer learning potential. For instance, a final exhibition created at the end of the semester showcasing the project work with physical models and posters from all groups, to which also students from earlier semesters were invited, was pointed to as a valuable platform that enabled knowledge building related to different design methodologies and communication strategies. This foregrounds the potential of working also with peer learning across semesters in order to establish a culture around peers that transgress a short-term learning horizon (Pelsmakers et al. 2020).

CONCLUSION

As Lawson emphasizes, designers gain an understanding of their subject "through the act of designing itself" (Lawson 2006). At CREATE the act of rehearsing design skills is conducted with and via groups of peers. In this context, the presented contribution discusses considerations and insights into peer learning dynamics within a PBL architectural education. The research question that was stated at the outset *"How can the didactical practice of*

peer learning in groups in architectural education contribute to address wicked design problems? Furthermore, what are the potentials and challenges of group work in the process of design?" led to several reflections.

On the one hand, there are several potentials towards peer learning practice: Students experienced increased motivation due to the allocated responsibility of being assigned the role as a peer. Another beneficial aspect refers to the possibility to practice working and discussing in a collaborative environment as well as enabling an interactive and iterative design process. Also, we could clearly observe that students' skills towards critical reflection, argumentation, and self-organization improved throughout the studied period. Also, their learning horizons shifted to include also long-term perspectives related to how investments of time and engagement into the collective learning culture benefitted the singular student beyond the given semester. On the other hand, we could also identify some challenges. These refer to an observed unbalanced engagement and active participation by students, potentially inherited from past experiences within a short-term oriented learning culture influenced by strict time and hand-in requirements. Another challenging aspect addressed the twofold mediating role of the instructor that needs to balance both key content points as well as interpersonal interaction among peer groups. Moreover, it has to be noted that it needs a certain effort to establish and mature a peer learning culture among both students and instructors, that takes also the physical attributions of the space, the material with which you learn, the provided guidance and thus the degree of alignment when it comes to inter-peer expectations into account. Overall, peer learning situations contribute to the students' learning trajectory. Consequently, coordinators and instructors have the possibility of enabling the maturation of a peer learning culture, where the learning and skills which mature within the individual students may not show themselves exactly within the situation and semesters you are in at the time, but rather matures over time and enables better design-making in advanced semesters.

The exemplary insights that have been alluded to above, show the didactic potential of peer learning in an architectural education within the framework of the pedagogical PBL teaching practice applied at CREATE. Such an approach could support sustainable, long-term, and deep learning in the field of architectural education that appears to be essential to develop skills towards being able to address wicked design problems.

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Material Knowledge and Digital Thinking: Reflections on Research-based Teaching

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ABSTRACT: Digital tools have become a part of most architectural education worldwide. Today, digital tools include much more than just drawing and modeling software. Every aspect of architectural design and development is digitized, and the component and construction industries are increasingly implementing digitization and automation. As such, digital knowledge and literacy in and around the architectural process are vast and constantly changing. While architectural education can include courses and implementations of certain digital tools, it seems impossible to teach all aspects of digital possibilities within the limited timespan of academic education. A strategy and didactic approach to the digital tool can guide the position of the educational institution and structure the ambition and intention of how digital competencies are brought to the students. Focused work on the digital curriculum at Aarhus School of Architecture led to a framework for digital teaching throughout the bachelor's and master's programs. A series of material- and research-based workshops for 2nd-year students were developed within that framework. This paper discusses the content of these specific hands-on digital courses regarding their intention and ambition as components in architectural education.

KEYWORDS: digital workflows, fabrication, education, workshop, wood

INTRODUCTION

From 2018 to 2019, Aarhus School of Architecture set out to update and reform its approach to digital teaching in its architectural education. A task force consisting of staff and faculty was formed to coin an overall strategy for the part of the curriculum that touched upon digital skills and literacy. Until then, digital teaching has been a vital part of teaching, but has consisted of fragmented initiatives without a larger didactic and academic framework. Courses dealing directly with specific software were part of the teaching, and a series of summer workshops included digital fabrication facilities. The focus for the digital curriculum initiative was eventually built around the term Digital Thinking. Digital Thinking is to be understood as critical thinking about how digital technology influences the design process, society, the built environment, and the architect's role. For the curriculum, this meant that the students should be presented with a broad palette of digital tools that can provide them with a high level of competency in using digital design methods and digital fabrication technology for architectural design. Translated into particular courses and workshops, this meant a gradual introduction of digital design and fabrication tools starting from the first year throughout the bachelor's and master's education. A special focus on design and making became a central part of each course, meaning that software, workflow, and digital tools should be taught and introduced to students in a way where the actual utilization of the procedures and possibilities is not predefined but instead an object for critical thinking and individual implementation. Digital fabrication methods allow architects to establish a closer connection between design and realization, as pointed out by Branko Kolarevich (Kolarevic 2004), and it was the ambition to introduce students to these potentials through hands-on experimentation. A series of digital fabrication-oriented workshops were developed in the Digital Thinking curriculum context. Again, the focus was on an open and critical approach to technologies, emphasizing workflow understanding rather than software procedures. Consequently, the workshops catalyze the question: How can workshop-based teaching inform and enrich digital skills and competencies in future architecture education? This paper unfolds a workshop trajectory that was developed with a focus on wood and an ambition of teaching students of architecture digital workflows through hands-on experimentation to understand the fundamental aspects of emerging technologies in architectural design and realization.

1.0 THEORY AND CONTEXT

1.1. Digital engagement

It has become increasingly apparent to the architectural profession that digital technologies have opened new forms of imagining and realizing architecture (Leitão, Castelo-Branco, and Santos 2019; Lidelöw, Engström, and Samuelson 2023). Besides offering new ways of designing, developing, and realizing architecture, digital tools differ from traditional tools in their volatility and pace of evolution (Arteta 2017). Whether the tools are hardware-based or software-based and whether they are targeted at designing, fabrication, or project management, constant

technological development demands attention and adaptability from the profession (Svetel, Kosic, and Pejanovic 2018). For architectural education, this also means that where traditional skills and techniques might have been taught through instructive and tutorial teaching (Fowles 1990), this way of knowledge transfer might have inferior long-term usability for digital tools. Instead, teaching digital literacy should be focused on enabling architecture students to understand and propose the handling of information relevant to the profession. As such, the ambition is to contribute to establishing computational design thinking, as lined out by (Ahlquist and Menges 2011). The most important digital skill might not be mastering particular tools but the ability to engage with and rethink data systems. This approach is aligned with Piaget's constructivist principles of learning, where meaning is created through experience and interactions with the environment (Jonassen 1991).

1.2 Digital literacy in architectural education

Several institutions worldwide have embraced digital media, software, or fabrication as the main elements or part of their education. The Architectural Association in London has its Hooke Park division – an architecture education where students live on a forest campus and, through a design-build education, construct wood buildings using both traditional craft and highly advanced digital design and fabrication tools (Mollica and Self 2016). On their Here East campus, UCL Bartlett offers undergraduate and postgraduate programs, with digital design, technology, automation, and manufacturing as focal points. At ETH, Zürich, and TU Munich, teaching formats revolving around full-scale realization through digital fabrication methods have been developed (Eversmann 2017). For such educational offerings, digital tools for designing and fabricating are both state-of-the-art and deeply integrated into the curriculum. While they and their likes are of great admiration and inspiration for other schools, they also position themselves as specialized educational choices.

For some architecture schools with a Beaux-Arts education background and anchoring, establishing an entire educational path built on digital skills might not be a choice or a possibility. Instead, the implementation of a common base of knowledge within the existing educational framework is the choice. This was the situation at Aarhus School of Architecture, where a common level of digital literacy was sought to be established among the students. Here, the strategy is not to enable all students to have the same skills but to inject a broad range of skills to stimulate diverse and vivid abilities. As such, Aarhus School of Architecture's relatively short digital curriculum elements should be regarded as exemplifying and of conceptual character, even though they have specificity, detailing, and themes that resonate with those of the more specialized schools.

2.0 RESEARCH

2.1. Material research

An ongoing research project was used to develop a series of digital workshops for 2nd-year students. The research project looked into the properties and capacities of wood, emphasizing developing ways of utilizing alternative wood resources. Alternative wood resources are, in this case, defined broadly as unused parts or species of wood. As such, the project seeks to investigate discarded wood elements from harvesting or sawmill facilities and look into the species and forms of wood currently not used in the building and construction industry. The main trajectory of this research project forms around crooked oak logs. Due to irregularities, a large amount of oak wood is discarded. However, through the methods suggested by the research project, these wood parts can instead be utilized when processed based on their divergence.

The research presents a workflow for handling the discrete shapes of natural saw logs in a system that involves collecting material, scanning/digitizing, handling a stockpile, computer analysis, design, and robotic manufacturing. The workflow includes multiple custom-made solutions for handling the complex and different shapes and data of natural wood logs in a highly digitized machining and fabrication environment. The suggested method is established by investigating wood as a material, studying the production lines in the current wood industry, and experimenting in our in-house laboratory facilities.

This up-cycling of discarded wood supply establishes a non-standard workflow that utilizes non-standard material stock and leads to a critical articulation of today's linear material economy. The research thereby gives an example of how sawlogs' natural forms and properties can be directly used to generate new structures and spatial conditions. A parallel trajectory in the research project concerns biodiversity and forest management. In this trajectory, a more diverse forest culture is sought, supported by more diverse use of different wood types. A fundamental issue here is again standardization in the industry. A better focus on individual wood properties and capabilities must be demanded to include a wider selection of wood species in building and construction. Regarding crooked, discarded, and alternative species, the research project argues for much better respect and utilization of natural properties, including fiber direction and mechanical properties.

2.2. Research-based teaching

The three individual workshops for architecture students formed a basis for a didactic strategy and reflection. The workshops are founded on the wood research project, in which selected content has been restructured to suit a 2-

week digital workshop format. The teaching includes a base layer of material knowledge concerning material properties and environmental aspects, and a layer of digital thinking that introduces design-to-realization workflows. The workshops contain hands-on material handling, digital analyses, production equipment (3D scanners, CNC machining centers, industrial robots, etc.), digitally driven design methods (parametric design, 3D modeling, and digital representation), and 1:1 machining and fabrication. Material work plays the lead role in these workshops. However, the materials and digital fabrication facilities are more to be seen as educational props for cultivating enquiring design methods and inventing digital workflows that bridge design and realization. The teaching is built around project development with software and digital tools presented as a pick-and-mix toolset.

The digital workshops started as teaching extensions of an ongoing research project. The students' work served as input and inspiration for the research project and provided insight into material-grounded architectural research.

3.0 TEACHING

3.1. Workshops

The first workshop was formed during the first phase of a newly started research project. The project had a quite open-ended research methodology where the material properties of wood resources were sought, investigated, and expanded through a range of digital workflows. However, when this first workshop was conducted, specific digital workflows and material processing procedures were deployed. The methods were aimed to digitize, and machine, discarded crooked oak branches and utilize those for architectural roof and truss constructions. These workflows and the ideas behind were presented and demonstrated to the students in their raw state. The students were then asked to develop their own uses and architectural investigations from the workflows. In this workshop, the students first went to a local forest where tree harvesting and thinning recently occurred; in groups, the students picked one or two wood logs that they found attractive. In all cases, these wood logs were curvy, crooked, branching or, in other respects, irregular. Back in the research lab, the student used the procedures from the research project of the 3D scan and developed a digital model of the found wood. For machining and processing, two workflows were available: Bandsaw cutting using a custom-built saw on an industrial robot arm and a 5-axis CNC machine. The students were asked first to split the wood pieces lengthwise using the robot setup and then next machine them on the 5-axis CNC with the aim of combining the members into architectural elements. In this regard, the students had total freedom regarding design and architectural intention, but when guided through common discussions and pin-ups during the workshop.

The students were motivated by the opportunity of engaging uniquely shaped wood materials in their design development. The outcome of the workshop showed architectural ideas that were quite different from those from the research project, even though the software and hardware workflows used were developed with a set of architectural components in mind. The ambition of enabling the students to use digital technologies and workflows from research in their formal and practical investigations was achieved.



Figure 1: Students 3D scanning a found wood log. Source: (Authors 2019)



Figure 2: Student positioning log in front of an industrial robot with a bandsaw. Source: (Authors 2019)



Figure 3: Three examples of architectural components produced by students. Source: (Authors 2019)

The second workshop had a different starting point. This workshop was not directly built on research developments but rather a parallel conceptual idea derived during the research project's progress. The idea was to use solid beech wood for joining between wood members instead of using steel brackets. The argument for this is that beech wood has material properties that make it extremely hard and generally has structural strength and static capacities around half the values of steel. At the same time, beech trees are a huge resource in Denmark, but are of almost no use other than a limited amount of furniture production. The students were asked to consider the material properties of the wood, including fiber direction, and invent a construction system with a beech joint as the key element. Both physical limitations of the 5-axis CNC and a gluing strategy for lamination are needed to inform their design decision. This workshop also implemented parametric workflows for architectural exploration, where the beech joint was the key part.

The students learned to experiment with the manufacturing technology and link it to the parametric design approach. The outcome was a series of different joint design solutions that, in different ways, proposed how to implement the properties of beech wood and the possibilities of 5-axis machining. The workshop took place at the beginning of a semester, where the following studies evolved around timber architecture, and the responsible tutors reported a higher degree of engagement in material and structural principles than would normally be the case when initiating the assignment without this type of workshop.

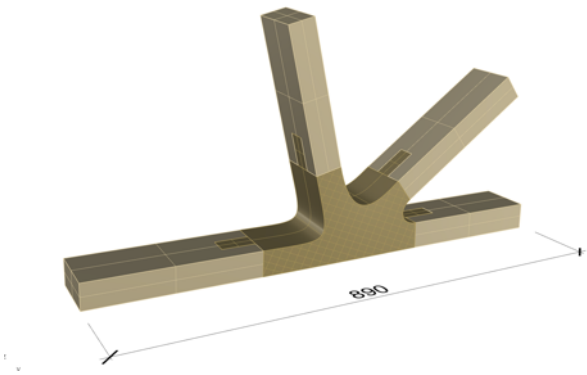


Figure 4: 3D model of beech joint connecting four pine members. Source: (Max Arpe-Sørensen 2020)



Figure 5: Student discussing glue strategy and fiber direction with carpenter. Source: (Authors 2020)



Figure 6: End-of-workshop exhibition of beech wood joint – prototypes and sketch models. Source: (Authors 2020)

The third workshop involving crooked oak was conducted after the conclusion of the research project. As such, it had partly the same conceptual foundation as the first workshop, but now with a much more developed and refined set of workflows and procedures. For that reason, it was decided to use the workshop to investigate and further develop the research. This meant the research project outcome became an example for the students, but with their task to test a new set of workflows still in development. The students were given crooked oak cut into slabs this time and presented with a photography-based digitization workflow and a machining workflow completely based on 5-axis CNC machining. Again, they were asked to develop architectural components based on their material and the possibilities of digital workflows.

The student's investigations reflected a deep engagement in the uniqueness of the given materials, and the results demonstrated a capability of handling the complexity and exploiting the material's aesthetic potential through the introduced workflows and technologies. This allowed a design-to-manufacturing process with high resolution in both the registration of the material and the specificity of the material processing. The outcome of this workshop was presented as real-size prototypes and parametric studies of a larger implementation of the students' concepts.

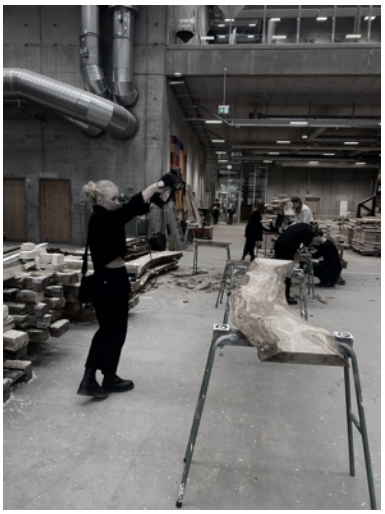


Figure 7: Student using handheld 3D-scanner to digitize crooked oak slab. Source: (Authors 2020)



Figure 8: Students monitoring 5-axis machining center. Source: (Authors 2020)



Figure 9: Digitized crooked oak slab and final transformation. Source: (Karoline Haugaard Rasmussen, Aase Eikeland Svendsen, Ragnhild Andreassen, Camilla Reiffenstein Christiansen, and Authors 2022)

The three workshops have similarities, where, the most apparent is that they are all concerned with the digital machining of wood. The machining workflow was quite experimental, e.g., the robotic bandsaw, and well-known, e.g., the 5-axis CNC. However, the computational and digitalization workflows leading to the machining were, in all cases, either custom-made or tweaked toward the research project. All workshops were presented to the students as very open-ended regarding architectural creativity and design possibilities but with very specific workflows and material interests as a foundation.

3.2. Reflection

The character of the workshops builds upon the idea of teaching skills to architecture students, which is different from the more tool-focused tutorial-based software course found within the educational domain. Where these courses often take a departure from a specific software and teach certain operations within that software, the described workshops instead largely build upon more experimental and less thoroughly tested processes. More dominantly, the workshops situate themself away from the classroom and instead inhabit the wood workshop space. As such, the digital workshop in question could appear more like workshop classes teaching craft or artisan skills. However, the claim is that the workshops are digital courses teaching 2nd-year architecture students fundamental computer skills for their education and future careers.



Figure 10: CNC-milled beech joints. Result of workshop 2. Source: (Various students and Authors 2020)

CONCLUSION

The three workshops were born at the intersection of a newly formulated digital curriculum intention and a research project with a strong focus and agenda. As such, they were both a test drive for implementing digital literacy throughout education and a way to transfer research developments into teaching. For both parts, the didactic focus and reflection were built upon conceptual thinking toward digital technologies and how these enable close design-to-realization workflows rather than expertise in specific tools. However, to do so, the specific tools became an essential part of all three workshops. This complex was never resolved as the evaluation of each workshop outcome was rather limited. Each workshop ended with an oral evaluation, but subsequent follow-up on the student's competencies was not carried out. Therefore, no data or indications are available at this stage, which gives uncertainty to the educational outcome of the workshop-based teaching. If the workshops provided the students with the intended critical digital thinking and literacy, they could transfer the workshop's learning to their own or other scenarios. If the teaching intention did not succeed, the student might have gained very specific digital skills focused on wood analysis and machining that might not be widely applicable. However, during the three workshops, it was noted that the students experienced how digital technologies enable the close interlinking of material, fabrication, and design, which was a primary learning goal.

ACKNOWLEDGEMENTS

All students who took part in the digital workshop are gratefully acknowledged for their engagement, openness, and contribution to the educational content of the workshop and this paper.

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Architectural Writing Laboratory: A Design Learning Experiment

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ABSTRACT: Writing is a spatial act - exploring different writing modes may unveil new modes of architectural thinking. When contextualised within the architectural framework, writing takes on a transformative role, capable of opening up possibilities for non-visual relationships and interconnected networks, thereby inviting critical inquiry and discourse. In architectural schools, where the design studio is the central focus, this area usually remains less explored, particularly in undergraduate programmes. However, practising architectural writing brings opportunities to students; for instance, they are introduced to and become familiar with spatial thinking in a literary space where their typically visual preconceptions do not operate.

Pursuing this perspective, this paper explores how effectively using writing as a design tool can uncover new and unconventional perspectives on architecture and proposes architectural writing as an interdisciplinary learning tool for guiding future architects and architectural design researchers. These issues are examined through an in-depth study of pedagogical objectives and outcomes of the *Architectural Speaking and Writing* course, a mandatory subject for third-year undergraduate students.

The course is structured as a writing laboratory that closely examines forms of architectural writing as primary instruments for finding a critical voice, engaging in critical dialogue, and communicating with the wider public. Through introducing the design of the course structure and analysing the writing exercises, this paper addresses the crucial role that diverse mediums and methods of expression play for students to connect their internal narratives with external realities in architectural education while altering the dominant position of the educator towards a facilitator.

KEYWORDS: Architectural writing, architecture education, architectural design research, critical thinking

INTRODUCTION

Architecture and writing alike participate in the imaginative creation of new worlds. They document and represent these realms, inhabiting and occupying them through projection. Both areas contribute to the establishment of settings for lives and narratives, recognising that every architectural proposal is essentially a form of fiction before it materialises. Similarly, every written fiction hinges on the construction of a coherent setting and context within which a narrative unfolds. Emerging from these intersecting possibilities, approaching architecture through the lens of writing forms a creative space, paving the way for unconventional considerations in architectural thinking and practice.

Visually-dominant architectural design tools may provide only a limited capacity in fostering and articulating design thinking, potentially neglecting non-visual dimensions within architectural discourse. This limitation not only narrows the scope of architectural pedagogy and practice but also underscores the critical role of architectural writing, which, by incorporating a situated perspective, enables a closer engagement with individual creativity while maintaining a necessary degree of critical distance. In this context, the inclusion of architectural writing may provide a valuable mechanism for addressing the shortcomings of visual-centric approaches and ensuring a more comprehensive exploration of architectural concepts.

From this perspective, the discussions advocating architectural writing as a design tool expand within the discourse of architecture. This expansion has been influenced by various conceptual and critical frameworks originating from diverse disciplines. Specifically, Donna Haraway's (1988) “situated knowledges” from science and technology studies, Elspeth Probyn's (1990) discourse on “locality” in gender and cultural studies, Jane Flax's (1991) “standpoint theory” derived from psychoanalysis, and Rosi Braidotti's (1994) theory of “nomadic subjects” within philosophy and feminist studies have contributed to this influential framework. All these nurturing discussions have drawn upon the notions of spatiality and positionality to explore concepts of subjectivity, situatedness, and materiality, intending to challenge dominant methodologies within their respective fields. These paradigm-shifting contributions have also amalgamated in the frame of architecture and lead to the emergence of many spatial and architectural writing experiments. Key examples in this context include “site-writing” by Jane Rendell (2010), the exploration of the textual artefact in architectural design research within the works of Katia Grillner (2004), “situated writing” by Mona Livholts (2020), and the development of the “ficto-critical approaches” in architecture by Naomi Stead and Hélene Frichot (2020).

Informed by the above mentioned discussions, we have restructured the Architectural Speaking and Writing course, a mandatory subject for third-year architecture students in the Spring term of 2022/2023. While the course was originally integrated into the curriculum with the objective of introducing students to the theoretical concepts and current debates in architecture, we believed that narrowing the focus towards architectural writing would foster architectural design learning of third-year students. The overall curriculum of the faculty has been shaped centering around the studio course, complemented by other courses supporting the studio's outcomes. Within this operational framework, our intervention in the course has served as an exploration of the potential role of architectural writing as a design tool, positioned to articulate students' design processes and studio practice.

In regard to students' extensive studio culture and experience, the course has been redesigned as a *writing studio*, a laboratory for spatial thinking and writing. This shift has meant a flipped approach, inviting students to be active participants, to be more precise, *active authors*. As third year students, they have already been exposed to many external truths and opinions; thus the reflective conduction of the course has posed a distinct challenge for them. Inspired by the situation, we have organised the course in three modules: (1) finding your own voice; (2) engaging in a dialogue/ encountering the other; and lastly (3) communicating with the wider public.

Each module consists of two weeks of lectures, one week featuring a guest speaker, and a minimum of two designated writing exercises to be held in-class. This structured format aims to provide a comprehensive learning experience by integrating theoretical content, real-world perspectives, and practical application within the course curriculum. The modules revolve around four core themes to be thoroughly internalised throughout the semester: interdisciplinarity, situatedness, subjectivity and critical inquiry. Although these themes are interwoven throughout the modules, each module is specifically dedicated to the in-depth exploration of a single theme.

In the first module, emphasis is placed on subjectivity as students actively engage in hearing their own voice and exploring their personal perspectives. This involves a reflection on how objectivity is constructed and the recognition that knowledge formation is influenced by acknowledging and multiplying one's standpoint. They are introduced to the concept of situatedness, highlighting its contextual relevance within architectural discourse.

Moving to the second module, the focus broadens to include both situated and interdisciplinary perspectives, involving other disciplines and other media in search of establishing dialogues with other voices. Concurrently, an introduction to critical inquiry provides a foundational ground for a deeper exploration of spatial debates and concepts.

The third module brings critical inquiry to the forefront. As students are tasked with setting up a dynamic critical distance towards their work completed throughout the semester, reflecting upon it, and proposing spatial curation, a revisit to subjectivity permits a deeper examination of personal viewpoints. This sequential structure is designed for a thorough and progressive engagement, mirroring the steps of an individual's journey to interact with the world around them: initially identifying their own voice, learning to amplify it, engaging with others, initiating a conversation, and ultimately sharing it with a broader audience.

Based on this approach, this paper explores the potential of writing, when employed as a design tool, to unveil new and unconventional perspectives in architecture. It proposes architectural writing as an interdisciplinary learning tool for guiding future architects and architectural design researchers. These issues are examined through an overview of pedagogical objectives of the abovementioned course modules and outcomes of modules' writing exercises.

1.0 RESEARCH DESIGN

Acknowledging the pedagogical value of architectural writing, this paper adopts a qualitative and exploratory research approach to examine the outcomes of the Architectural Speaking and Writing course, held during the Spring term of 2022/2023. The course was modified to accommodate a hybrid learning model due to earthquake-related conditions in Turkey. It engaged a cohort of 86 students, providing them with the option to attend either in person or through online platforms. Spanning 13 weeks, the curriculum was structured into three consecutive modules, each covering an intensive four-week period.

As above mentioned, the course is structured as a writing laboratory that closely examines forms of architectural writing as primary instruments for, firstly, finding a critical voice; second, engaging in a dialogue; and third, communicating with the wider public. The first module probes the roles of authors and readers, delves into narrative constructs, and investigates the dynamics of reader-writer relationships. Transitioning to the second module, the focus shifts to learning to effectively communicate with diverse entities, be it people, places, objects, or situations. The process involves viewing these entities as complex components, seeking mutual comprehension, and collaboratively generating solutions. This module prioritises engaging in a dialogue with the other and aims to design writings where both parties of the dialogue can equally be heard. In the final module, the emphasis lies in extending communication beyond the self and engaging with the external realm - the wider public, and the built environment.

These modules are founded on active participation of the students via specialised writing exercises to allow students to critically assess and cultivate creative approaches in their own design thinking processes, building upon the insights gained from other courses within the architecture curriculum. In the writing exercises of the first module, students discover various uses of media as a tool to represent and expand their design ideas and encounter non-

linear narratives. They reflect on their subjective experiences, by *revisiting a memory space*, to develop objective spatial information without using presumptive language. In the later exercises, they are introduced to the specifics of curating media with guest speakers, and engaging in a dialogue through on-site writing excursions to exhibitions, such as *Istanbuls today* at the Pera Museum, before they are asked to design a *reading room* - an interface between the physical medium of their productions and the literary medium of their conceptions.

This paper explores the significant impact of varied mediums and methods of expression in architectural education, facilitating students' ability to bridge their internal narratives with external realities. By presenting the course design, objectives, and outcomes of specific writing exercises, it highlights a shift from the traditional educator-dominated approach to a more inclusive role of the educator as a facilitator. The following sections delve into the structure of the three modules, showcasing a writing exercise from each to illustrate how these strategies enhance learning.

2.0 MODULES

2.1. First module: finding your own voice – revisiting a memory space

Finding one's own voice is an expression that refers to the process of discovering and expressing one's unique perspective, opinions, and individuality. In various contexts, it can involve developing a distinct writing or speaking style, expressing personal values and beliefs, and articulating thoughts and ideas in an authentic and genuine manner. Finding one's voice often involves self-discovery, reflection, and a conscious effort to communicate in a way that individuals navigate societal expectations and stereotypes to articulate their authentic voices. To achieve this, students delve into concepts such as multivocality, intervening into narrative, reader/writer relationships in this module.

After exploring the shifting roles between the author, the reader, and narrative constructs, the first module concludes with an in-class assignment titled *Revisiting a Memory Space*. This exercise is designed with several key goals: to introduce students to writing place, to foster experimentation in forming tempo-spatial narratives, to encourage students to situate themselves in writing, and to enhance their understanding of subjectivity in writing. To effectively meet these objectives, students were encouraged to skilfully blend both imagery and textual elements in their writing.

For this assignment, students were given the task of selecting and bringing a childhood photograph. The guidelines stressed the importance of their visible presence in the photo, set against a backdrop that is identifiable and meaningful, be it an indoor or outdoor scene. This specification was deliberately set to avoid generic, featureless studio backgrounds, thus enhancing the depth, context, and emotional resonance of the photographs. Furthermore, to add layers of narrative and texture, students were also encouraged to supplement their photographs with any visual or textual elements, such as maps, tickets, or other items, that hold a connection, whether direct or suggestive, to the location captured in the photograph. Students had the flexibility to work with either original materials or their digital reproductions, bringing in physical items or scanned copies.

In this exercise, students revisited and reinterpreted a cherished memory space. Utilising a blank piece of paper, they were tasked with the challenge of articulating and reconstructing the space in their memories through text. The exercise began with a crucial reminder: memory is inherently non-linear, and remembering is a non-linear process. Students were thus encouraged to embrace this fragmented, disorderly nature of recollection, allowing for non-linear storytelling to more deeply understand and reconnect with their past experiences.

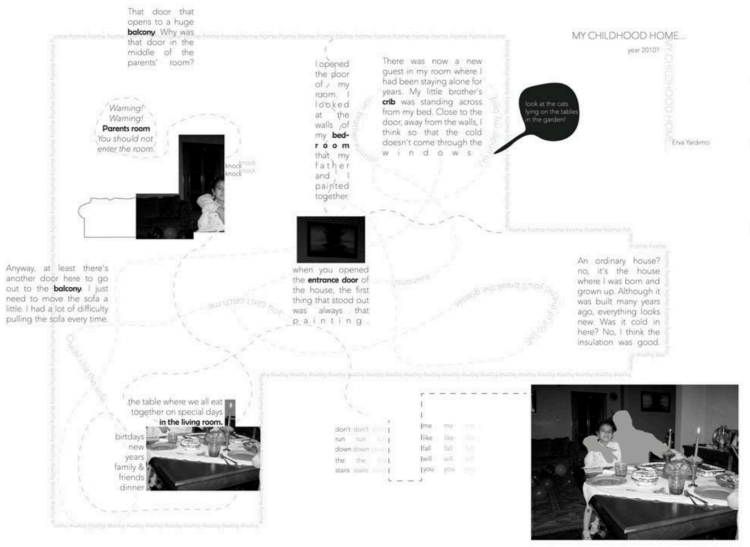


Figure 1: Revisiting a memory space by E. Yardımcı. Source: (Yardımcı 2023)

For instance, E. Yardımcı's employed the spatiality of paper-space to recreate the house from her childhood, where she resided with her family (Figure 1). Concentrating on the sensory and detailed fragments embedded in her

memory, the act of writing served as a tool to organise these fragments spatially. This involved the utilisation of various writing elements, including different line weights, font characters, and text styles, contributing to a nuanced and spatial representation of her recollections. In her exploration, she delved into a fragmented representation of space across multiple layers, covering the physical space, the recalled space, and the narrated space. This approach allowed for an examination of the interplay between the tangible, sensory, remembered, not-remembered and narratively constructed aspects of the space in question.

Moreover, students were free to integrate additional textual and visual elements into their work. These elements served as catalysts in recalling and reconstructing the narrative fabric of the memory space. To facilitate this, the use of diverse media forms was strongly encouraged, aiming to trigger their memory and enhance their spatial thinking. An intriguing example of this was found in S. Düzenli's work (Figure 2). She superimposed her inner voice from childhood, her narrating voice describing the remembered memory, her observational voice from the recollected moment, and the external voices present in her memory. Within this intimate conversation, she disentangled fragments of visual elements and the visual use of textual elements. These components were then strategically separated, placed in varied scales, and subjected to different spatial orientations. This exploration allowed her to construct distinct spatial versions of her childhood room in the minds of readers with each successive reading, all while preserving the atmospheric and narrative information.

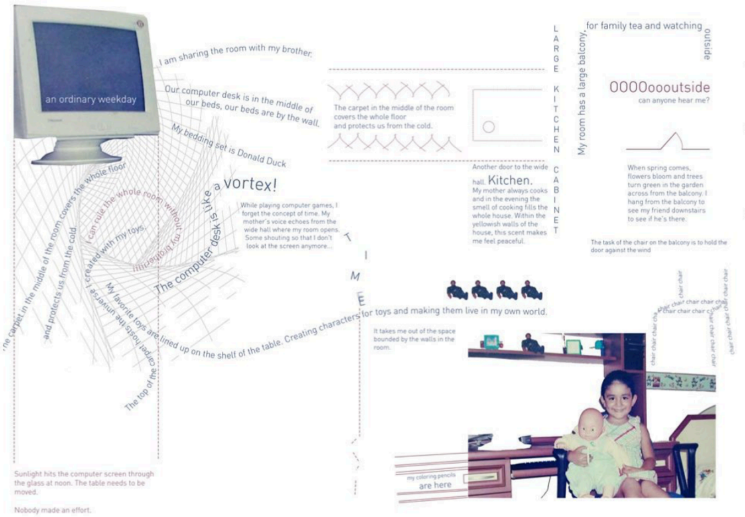


Figure 2: Revisiting a memory space by S. Düzenli. Source: (Düzenli 2023)

2.2. Second module: engaging in a dialogue – Istanbuls Today at the Pera Museum

In the second module, titled *Engaging in a Dialogue*, students pivoted to learning effective communication across various entities such as people, places, objects, or situations. Beyond maintaining a space for free expression, a dialogue necessitates carefully hearing multiple voices to facilitate meaningful expression. For this reason, the content of this module aimed to instrumentalise writing as a means to initiate encounters with other disciplines, express perspectives from diverse locations and viewpoints, write through architectural elements, and employ spatial tactics such as framing-reframing, filtering, observing, and gazing in relation to critical writing.

The module culminated in a writing trip to the *Istanbuls Today* exhibition at the Pera Museum. Curated by Refik Akyüz and Serdar Darendeliler, this photography exhibition captured a critical and creative visual interpretation of our current era. It also served as a vibrant platform for artists to showcase their diverse interpretations of Istanbul. This assignment was designed to evoke and encourage students to embrace the roles of both writers and critics. Each student was asked to choose one artwork that resonates with them the most after visiting the exhibition and write a text that converses with the chosen artwork and overall exhibition in order to unveil their own *Istanbul today*. The purpose of this writing trip was not solely to produce a critical piece on an artwork or the exhibition; rather, it was about initiating a dialogue with them. Each student could then use this dialogue as a catalyst to reflect on their multilayered experiences and opinions about the city they lived in. To stimulate thought, we also provided students with pre-class material: Jane Rendell's (2005) catalogue essay, "On thinking I am missing the point", written for artist Sally Morfill's works. This essay was instrumental in helping students think about the interplay between writer, artwork, and the text produced based on an artwork, before engaging in their writing exercise.

This exercise took place when a hybrid learning model was in effect due to earthquake-related measures in Turkey. Consequently, students had the option to either visit the exhibition space in person as a group or explore the virtual gallery individually. The physical and digital interfaces of exhibition spaces became a distinctive feature of the texts. For those who were able to attend the writing trip online, the assignment unlocked an additional challenge: to consider how this hybrid format influenced their writing process and to reflect on the nature of digital exhibition viewing. In the texts produced by these students, their spatial experience unfolded within different temporal and physical settings. They wrote about how digitally visiting an exhibition allowed them to conduct research on the topic and artists simultaneously. Using a mouse instead of their feet altered their physical engagement with the exhibition. A notable example illustrating these distinctions is evident in E. Nakip's text, as shown in Figure 3.

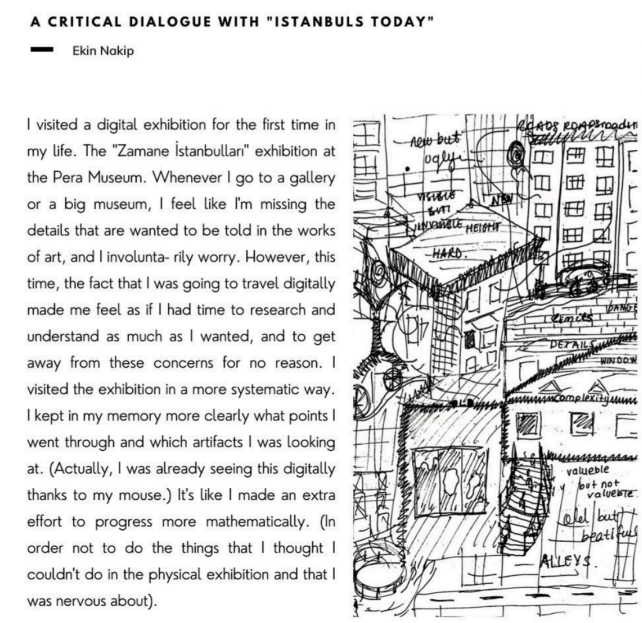


Figure 3: A critical dialogue with “Istanbuls Today” by E. Nakip, digital exhibition visit. Source: (Nakip 2023)

These differences sparked creativity and resulted in a diverse range of outcomes for the assignment. The real-time Istanbul experience added another conversational layer in the texts of those who physically attended the exhibition. In D. Yücaltı’s text, for example, she intertwined the narrative of the artwork she chose with her inner voice incorporating real-time external conversations from passersby. She accomplished this by capitalising on the exhibition's central location in Istanbul within her text.

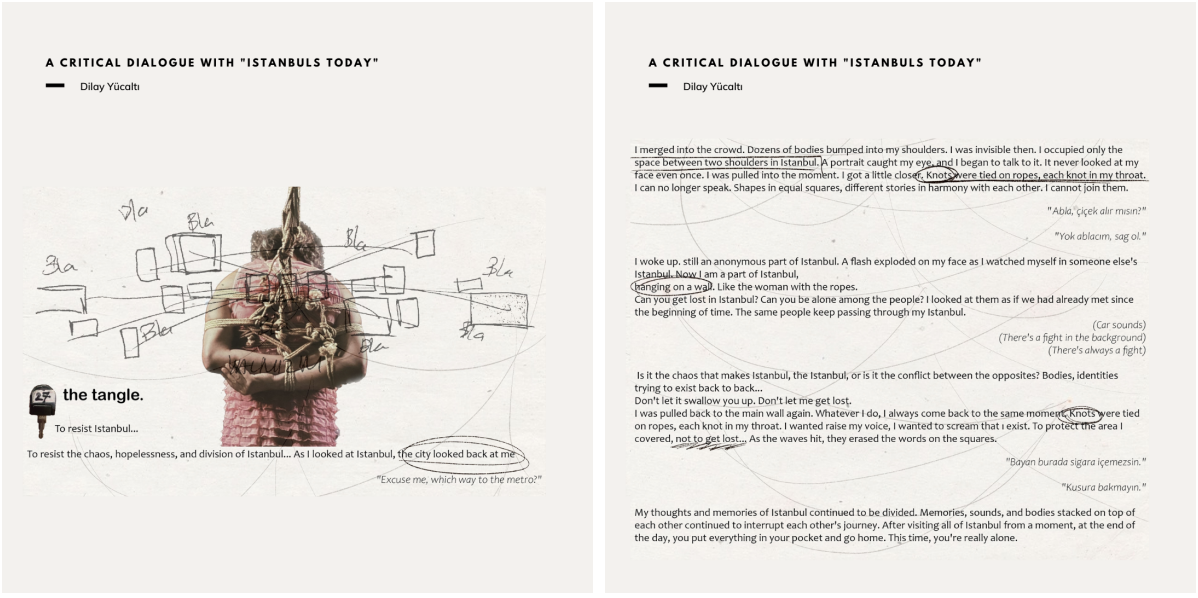


Figure 4: A Critical Dialogue with “Istanbuls Today” by D.Yücaltı, physical exhibition visit. Source: (Yücaltı 2023)

In terms of content and layout, the exercise encouraged students to think about the concept of "Istanbul today" as portrayed in the exhibition. Comparing the represented Istanbuls with their personal experiences enriched their critical approach. The contemplation triggered by the artworks and the assessment of the curation's ability to uncover different layers of Istanbul aimed to elicit thoughtful insights into the city's multiple identities. Overall, the exercise was designed to encourage an exploration of both the physical and digital dimensions of the exhibition, seeking to unveil a personalised yet detailed understanding of Istanbul today.

2.3. Third module: communicating with the wider public - reading room

In the final module, the focus shifted to broadening the scope of communication, moving beyond personal expression to interact with the wider world, including public audiences and the built environment. Students explored the intricacies of curating media through interactions with guest speakers and practical experiences, such as on-site writing excursions. This hands-on approach provided them with valuable insights and skills in media curation.

A key assignment in this module was designing a *Reading Room*. This exercise served as a tangible bridge linking the physical embodiment of their work with the literary expression of their ideas. The task involved creating a

compact, yet immersive, 1m^3 pop-up space, designed to engage with and reflect upon the students' semester-long work. This space was to house various materials: in-class submissions, pre-class questions related to reading materials, and a collection of sketches and notes compiled throughout the semester.

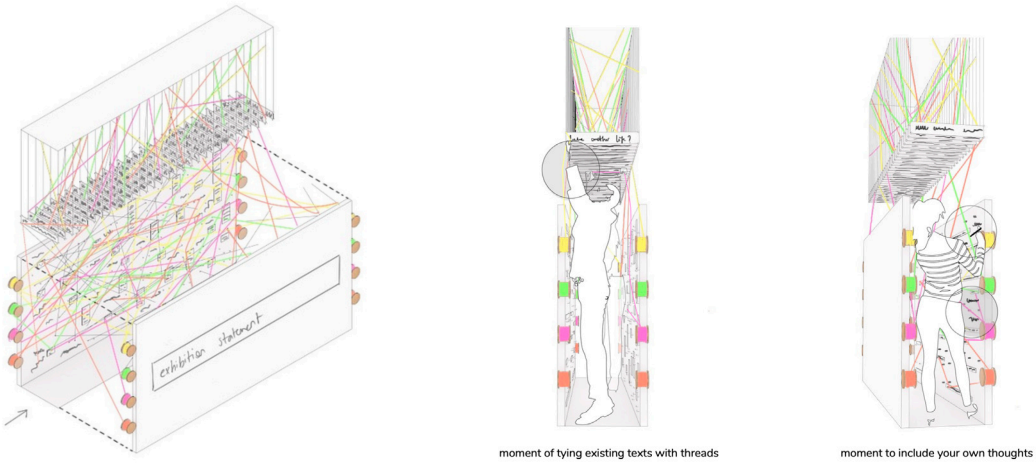


Figure 5: "Dialogue Paths: In Search of Ideas" by G. Helvacıoğlu. (Source: Helvacıoğlu 2023)

As the final assignment, this work differed from the previous assignments as it centred on spatial design more than designing writing. It asked questions on how effectively the created space facilitates the reading and performing experiences of the showcased works. Following all these agendas, it also played a crucial role in assessing whether the course and architectural writing had an impact on their architectural design approaches or not. The exercise challenged the students to not only conceptualise a physical setting, but also to carefully consider how the spatial arrangement contributes to the interpretative and performative aspects of their academic works.

Yet, it was influential to observe how students contemplated the material translations of their literary design works and endeavoured to utilise space as an interface for conveying written content. Notably, there were attempts to integrate design elements to enhance overall engagement with the exhibited materials, as one of them exemplified in Figure 5. In G. Helvacıoğlu's reading room design, it was possible to trace the reflection of the course outcomes on spatial design. In her proposal, she suggested nonlinear spatial experiences created by multi-colored strings, considering both the writer's position and the readers' positions. Through reader engagement, these strings formed sentences that could alter, rooted in her written works, transforming the exhibited materials into *open works*. This not only enabled an ever-changing atmosphere and an active reading experience but also prompted an investigation into the material translations of multivocal spatiality.

Overall, the final works involved a careful examination of the core themes discussed throughout the semester. Additionally, they reflected on the module structure by defining their own positions, contemplating various perspectives, engaging with others, and participating in multidisciplinary thinking processes.

CONCLUSION

Over the last decades, architectural writing has become an effective tool for architectural thinking and practice. More specifically, exploration of subjectivity, situatedness, interdisciplinarity and criticality through spatial and material qualities of the text brought writing closer to architectural design processes (Rendell 2013). This recognised a new understanding of architectural design research through architectural writing and inspired us to form a theoretical architectural course which prioritises finding a critical voice, engaging in a dialogue, and communicating with the wider public within the context of architectural design. Based on our exploration within this course throughout the Spring term of 2023, we have come to the following key observations:

- Students' efforts to construct narratives based on personal experiences significantly enriched their architectural thinking and design approaches. Such writing exercises have the potential not only to improve their creative potential but also to develop their skills in participating in and contributing to architectural discourse.

- Effectively using writing as a design tool enabled students to comprehend a place through its multifaceted layers, offering a richer, more nuanced understanding of the spatial context. This approach can inspire original architectural ideas and narratives by incorporating elements such as memory and experience, encouraging a shift towards hybrid representations from popular visual-centric approaches.

- This course is placed at the end of the third year in the architectural curriculum, a period by which students have become notably opinionated in architectural subjects. Adopting a fresh perspective through architectural writing can potentially diminish the inclination towards popular themes that dominate the architectural discourse while amplifying curiosity in topics that are less explored or previously unspoken.

This study shows that using writing as a design tool in architectural education can significantly unveil new and unconventional approaches. It promotes interdisciplinarity, encourages critical thinking, and embraces subjectivity, thereby guiding future architects and architectural design researchers. Nevertheless, these findings stem from a limited dataset, and further studies are essential to analyse how this influence and growing importance of architectural writing transforms architectural thinking and practice. Therefore, following this paper, structured experiments will be conducted with architecture students to study the impact of architectural writing in greater detail.

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The Climate HubLAB at NTNU

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ABSTRACT: The identification of sustainable design with the use of standards and commercially available components for energy efficiency has led architecture students to suddenly become more concerned and thirstier for existing know-how, rather than developing the ability to observe and generate their own solutions. Sustainability in architectural education cannot be limited to making students aware of environmental challenges and ready-made solutions, neither into limiting environmental impact on a purely numerical basis. We need instead to shape architectural practitioners able to use their creativity and imagination to shape new architectural paradigms re-harmonizing natural and built environment. Throughout the MSc program in Sustainable Architecture at NTNU, students rely on different kinds of software to optimize environmental performance and minimize environmental impact of their projects. Teaching experience show that an extensive use of simulation software risk anyway of simplistically reducing complexity behind sustainability to a discreet number of parameters. Question is therefore how results provided by advanced simulation tools can be combined with a holistic understanding of the process. The Climate Hub-LAB, developed thanks to the support of the AVIT program at NTNU, aims at providing students an integrated studio where flow of information coming from different machines and tools, can be collected, and more effectively translated in efficient architectural design concepts on the basis of hands-on experiences. In this paper we will reflect on the the use of digital tools and their role for supporting the development of hands-on activities fostering creativity and imagination.

KEYWORDS: experimental, bioclimatic, design, laboratory, studio

INTRODUCTION

In the last century, the anthropization of the natural environment, together with the human interference with the natural climatic system, have determined a significant rise in global temperatures. Scientists seem to agree that global warming is mostly caused by an increasing concentration of greenhouse gas emissions in the atmosphere. Buildings, throughout their life cycle, are responsible for over a third of greenhouse gas emissions due to anthropogenic activities (Buildings and Climate Change Summary for Decision-Makers 2009). According to the United Nations, to limit global warming within the threshold of danger of 2°C, greenhouse gas emissions due to buildings should be cut by 90% within 2050 (UN framework on climate change. 1992). Such an ambitious target has fostered, in the last decades, the technological development and diffusion of innovative materials and components for energy efficiency. The identification of sustainable design with the use of standards and commercially available components for energy efficiency has led architecture students to suddenly become more concerned and thirstier for existing know-how, rather than developing the ability to observe and generate their own solutions. Sustainability in architectural education, however, cannot be limited to making students aware of environmental challenges and ready-made solutions, neither to making them able to limit environmental impact of the built environment on a pure numerical basis (Finocchiaro 2018). Instead, we need to shape architectural practitioners able to go beyond energy and emissions accounting, to create new architectural paradigms with the purpose of “re-harmonizing natural and built environment” (Dan Chodorkoff 2014).

1.0 SUSTAINABILITY IN ARCHITECTURE EDUCATION

The MSc program in Sustainable Architecture at NTNU is based on the assumption that the ability of handling multidisciplinary processes cannot be taught simply by assigning multidisciplinary tasks to students but needs to be experienced, taking part in multidisciplinary projects and teams. For this reason, the program is open to both architects and engineers, called to collaborate in the design of buildings characterized by minimum environmental impact. In the first semester students are trained in environmental performance analyses and the design of bioclimatic shelters; in the second semester, students are introduced to concepts such as durability, life cycle, and recyclability. In the third semester, environmental performance is related to the use of energy systems and renewable energy. Simulation tools are used to model indoor climate and buildings´ energy demand, while BIM models facilitate accounting of materials’ and related emissions. Besides undeniable advantages when dealing with complex computational analysis, an extensive use of simulation software seem to simplistically reduce sustainability to a discreet number of numerical parameters. Moreover, the most courageous and innovative proposals, generally based on intuition and students´ tacit knowledge, are the most difficult to simulate. Therefore, students tend to prefer to either follow a purely qualitative approach, allowing them to further explore their innovative ideas and visions, or abandoning courageous ideas in favour of more numerically convincing analyses. For this reason in 2013 we sketched the concept of an integrated laboratory for environmental performance analyses that could facilitate the relation between analog and digital tools, between the creative and rational side of the brain. Such a concept is represented in Figure 2.

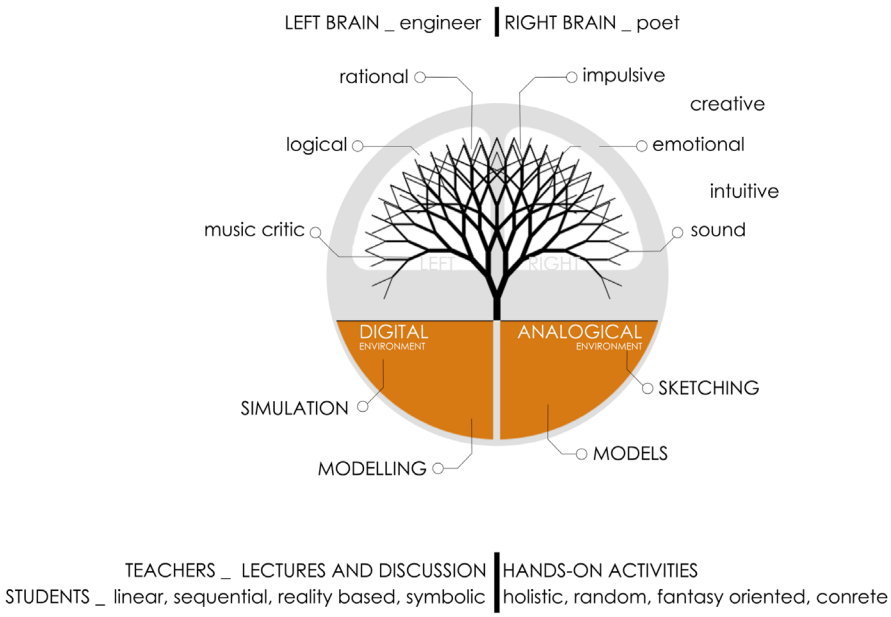


Figure 1: A reasoned use of analogue and digital tools in the program aims to let students train in understanding and relating quantitative and qualitative parameters in creative form-finding processes. Source: (Assembled by the authors 2018)

1.1 The "Climate HubLAB"

By the time an advanced simulation is run, architecture students are commonly able to produce a discrete number of physical models or sketches where an indefinite number of logical connections are summarized. Research suggests that hands-on activities, such as sketching and model making, still represent a powerful tool for processing knowledge and grasp theory (Fernandes et al., Heineman et al., Sunalini et al.). Question is therefore how to combine digital and analog tools in a way to take advantage of the computational capabilities of the first, while exploiting values of hands-on approaches for handling holistic design processes and enhancing students´ learning environment. With this purpose, in 2016, thanks to the support of NTNU, we could initiate the development of the Climate HubLab (figure 3 and 4), as a pedagogical laboratory collecting analog machines for environmental performance analyses of different kinds (such as heliodons and streamlines visualization tools) and equipment for facilitating the transfer of information between the digital and the analog environment.

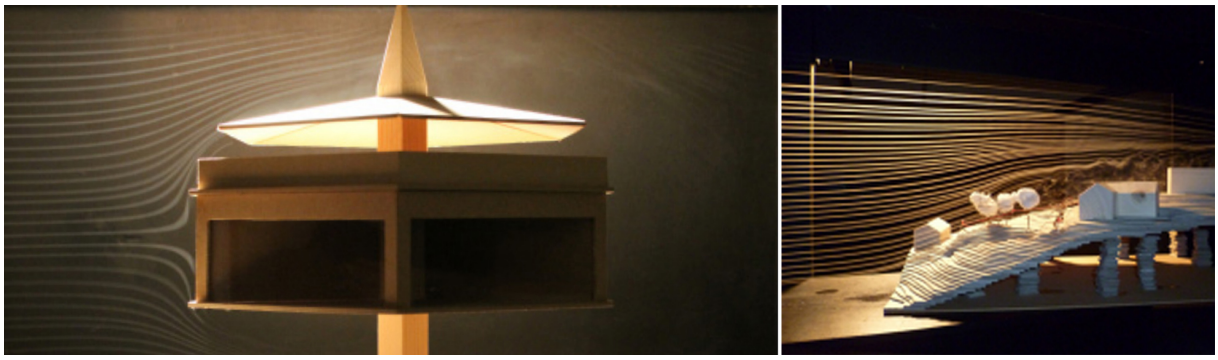


Figure 2: Student testing an architectural model of the Dymaxion house of Buckminster Fuller and a section of a house in the landscape during their project development. Source: (Assembled by the authors 2018)

The ultimate intention of the climate HubLab is that of transforming courses in climate and built form into an experimental pedagogical arena where theory is grasped by involving students in a series of hands-on activities or experiments were analog and digital tools are balanced in a reasoned way. This transition required first of all the transformation of the design studio into a laboratory where students could freely experiment with knowledge and customize experiments to validate their visions and concepts. Besides this, it was necessary to:

- understand how digital tools could be used not only for their computational capabilities but also to enhance the learning potential of hands-on activities.
- facilitate the transfer of information from the analog to the digital environment.
- moving from cumulative to formative assessment practices, giving space to "learning from failure".

This paper reflects over the role of the lab for the transformation of the course into an experimental arena for testing innovative design processes and their potential for pedagogical activities. Reflections hereby described have been built over experiences gained during the last ten years of teaching bioclimatic design at NTNU and are supported by results of an experimental workshop conducted with the help of a PhD student, focusing on pedagogics of environmental design and involving students, teachers and a pedagogist. The workshop, developed inside the courses on climate and built form, focused on the use of analogue and digital tools for bioclimatic design, with an insight on their beneficial or adverse role for creatively handling holistic architectural design processes.

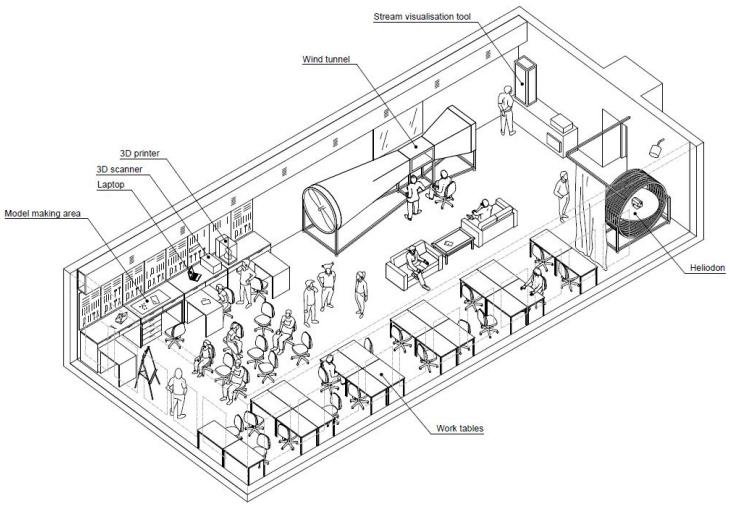


Figure 3: The climate HubLAB at NTNU was conceived and developed with the purpose of exploring the pedagogical potential of equipping conventional design studios with equipment for testing physical models. Source: (Ilya Pugachenko 2018)

2.0 THE EXPERIMENTAL WORKSHOP

Since 2013, courses in “Climate and built form” have been structured in a sequence of pedagogic modules where theory, generally transferred through a lecture, was used as the basis for the use of digital simulation tools. A comparison between grading in the theory and in the design course, conducted from 2010 to 2014, showed however that students could master knowledge in climate adaptive design without necessarily developing the ability to apply it in practice. For this reason, from year to year, focus on the development of the pedagogic modules moved from content to the process of learning: from refining knowledge transferred through lectures, to the development of activities that, following experiential learning theories (Kolb 1984) could enhance student learning.

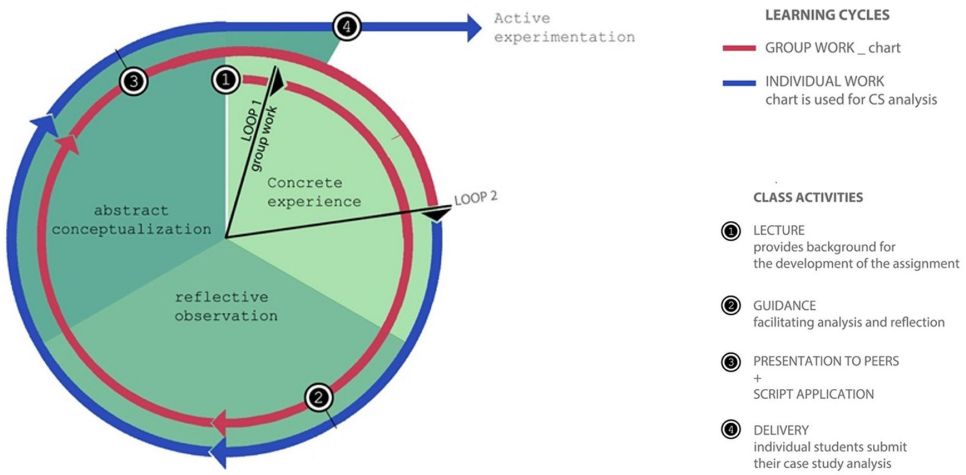


Figure 4: A graphic representation of teaching and learning activities in the revised pedagogic model run in the form of experimental workshop in 2023. Source: (Assembled by the authors 2024)

In 2023, with the purpose of analyzing the pedagogical potential of combining analog and digital tools for environmental design, we designed an experimental workshop where digital tools were used to support the learning potential of hands-on activities, rather than as mere computational tools. The workshop focused on the revision of the pedagogic module about “sun and form” and students were asked to question and reflect over specific aspects of their project through a series of experiments. The workshop was developed as an intensive experimental activity of the regular design course where students, distributed in five different climatic conditions, were asked to design a prefabricated climate adaptive shelter for post disaster recovery. Concepts were developed on a purely intuitive basis in the time of one week before the workshop started. In defining the concept students had to compromise specific functional and dimensional requirements while embedding solutions for improving the project environmental performance, involving form, construction, and systems to employ throughout the year. In this stage students were asked to only look at climatic data without building any model for digital simulations. Once concept was developed, students were asked to expose their concepts to three experiments, where the first and third were based on hands-on activities, and the second one on the use of a digital parametric modeling tool. In the first step, students were asked to formulate three climate-specific questions to investigate using a manual heliodon (i.e. optimize form to

minimize self-shading; identify orientation ensuring maximum exposure in winter, etc.). In the second step, students were asked to use a digital script for relating the morphological characteristics of their project to the assigned climatic context on quantitative basis. Finally, students were invited to run a more detailed analysis in an automated heliodon equipped with micro-cameras to analyze solar access and adjust detailed components within the project (i.e. distribution of thermal mass, effectiveness of a solar shading system, etc.).

Each step in the workshop was structured following the four steps internal to the experiential learning cycle. Looking at the second step, for instance, (1) by using the script students would get a concrete experience about the use of simulation tools for morphological optimization; (2) the results would give them the possibility to reflect over their proposals, being able to quantify implications of choices taken in the concept stage; (3) comparing numerical result and their concept morphology, students can now more easily abstract principles for climate adaptive design and (4) enter an active experimentation stage where they can more consciously adjust form of their project on the basis of knowledge gained through the processed experience.

The second stage of the workshop represented the only “digital step” in a sequence of hands-on activities, involving sketching, model making and testing in two different kinds of heliodons. The original pedagogic module about sun and form in the course aimed to equip students with the ability to calculate and analyze heat quantities in a building. Through digital simulation tools, students could analyze heating and cooling demand as the result of the building thermal budget and adjust morphological characteristics in a way to increase solar intake or construction and schedules to improve airtightness or facilitate natural ventilation. The limit of such an approach was that of working on refining a form without being aware of how much that form is close or not to the ideal, or optimal, one, in terms of thermal balance. For this reason, in the digital step of the experimental workshop, we decided to develop a code that could make it possible to identify the optimal form on a numerical basis. The script was developed following the sol-air approach, as defined by Victor Olgyay (Design with climate 1963) according to which the optimal form of a building is the one able to take maximum advantage of solar radiation whenever temperatures are below the comfort zone, while ensuring minimum intake while outdoor temperatures are above it. In this second stage, thanks to a premade script in grasshopper, students could calculate the optimal proportions and orientation of a hypothetical box in the specific climatic context where they were working. This exercise was voluntarily included as an intermediate step such that students would rather use this piece of information to reflect over their proposal, developed on a purely intuitive basis in a more holistic setting. Students would be exposed to learn from failure and adjust the form, rather than get a specific answer from the computer at the beginning of the process and risk to not use their own critical abilities.

2.1. Results

To evaluate the impact of the revised digital module on students’ learning we looked at experiential learning theories while taking advantage of action research methods. Before the workshop, students learning style was mapped following Kolb’s theories (Kolb 1976) asking students to fill a questionnaire about their attitudes when approaching learning tasks. During the workshop, action research methods were used as “a form of systematic inquiry, prioritizing reflection and bridging the gap between theory and practice” (Selener 1997). Following action research methods, we did not only observe but interacted with students and intervened whenever a good opportunity for learning arose. Finally, after the workshop, we collected relevant feedback from students through a questionnaire and an interview in design groups.

Results of the workshop’s analyses are collected in Table 1. The upper part of the table was developed over the analysis of the material delivered by students and complemented with information collected during the interview. In this part it is described how students approached the use of the digital script, if the experiment provided unexpected results or supported a more holistic understanding of “sun and form”, a reflection or a design choice influencing the design process. Finally, it is also added a mark whenever the digital module opened to more active experimentation. In the second part of the Table, it is collected other relevant comments given at the interviews about timing, concept, and administration of the workshop.

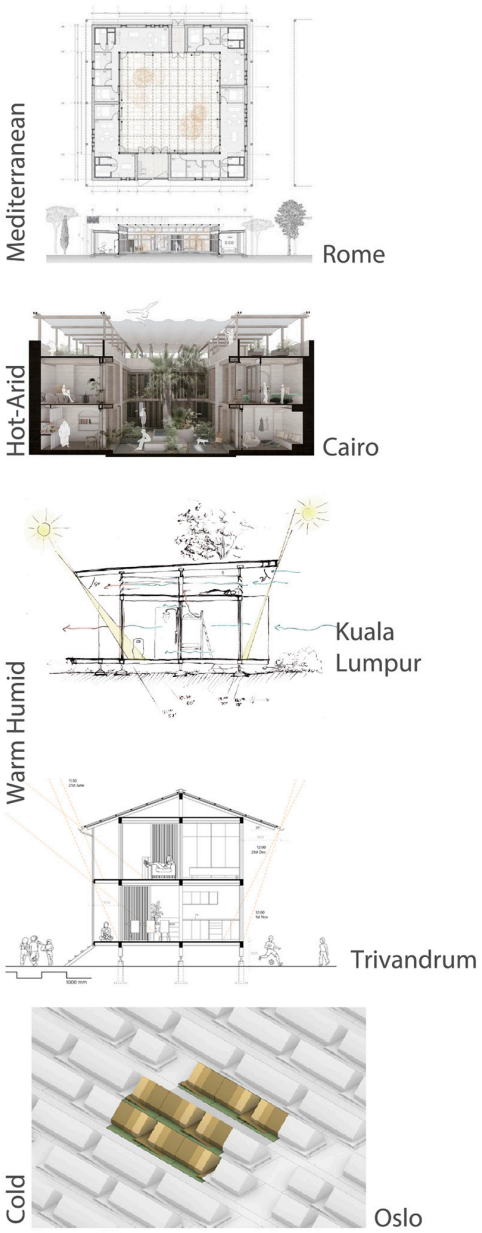
Besides it is not easy to identify a pattern in the analysis of the results, a few reflection points can be drawn. Four of five groups made use of the digital script developed based on the sol-air approach to relate their proposals to the optimal as calculated following the sol-air approach. Only the group working in the cold climate of Oslo recurred to a different software. Students working in the hot-arid and Mediterranean climate, where shading in the overheated season is a relevant concern, claimed to have used the script to test alternative solutions and came into unexpected results that affected their design choices and process ahead. People working in warm-humid climatic contexts such as Kuala Lumpur and Trivandrum, where houses needed mostly to be shaded from the zenith and where natural ventilation and wind patterns played a stronger role for the concept development, got a broader understanding of climate adaptive design issues related to sun and form; none of them claims that the experiment influenced their design process anyway. The group working in the cold climatic context of Oslo, focusing on maximizing passive solar heat gains, used the script to identify the proportion of the ideal box in their climatic context but preferred to leave the project as originally planned (anyway close to the optimal) because of other concerns related to aesthetics and prefabrication of the project.

The groups working in Rome, Kuala Lumpur and Oslo wished that the digital tool module could be implemented earlier and, among them, students from the group working in Rome felt that the digital tool limited their creativity and possibility for exploring alternative design solutions. Together with them, the group working in Trivandrum reported that the digital tool was more difficult to grasp than the use of heliodons and four out of five groups preferred hands-on activities to the digital module.

It is important to notice that only groups working in Rome and Cairo claimed to have used the script to test alternative design solutions, developing choices that affected the design process forward. This might be due to the fact that the climatic context, in comparison to others, resulted more inspiring and brought them to unexpected results that were then translated into concepts. Evaluation criteria of the design course prized anyway those projects that gave evidence of a systematic effort for the adaptation of their projects to climate and context and those two projects seemed to have gained the most from the experimental arena tested in the workshop.

Table 1: A resume of the analysis of the workshop showing a reflection over activities and feedback provided by students, together with students projects on the right side. Source:(Assembled by the authors 2024)

		Rome	Cairo	Kuala Lumpur	Trivandrum	Oslo
Experiment	initial design	●	●		●	●
	bondary conditions	●		●	●	●
	alternative solutions	●	●			
Discovery	as expected	●		●		●
	unexpected	●	●		●	
	broader understanding			●	●	
Reflection	initial design	●		●		●
	on discovery	●	●		●	
	on possible solutions	●				
Design choice	due to experiment	●	●			●
	due to discovery					
	due to reflection	●		●		
experiment influenced the project development		●	●			
Followed more active experimentation on Sun and form		●	●	●		●
Feedback	wished the digital script earlier	●		●		●
	the digital tool limited my creativity	●				
	digital tool was more difficult to grasp than heliodons				●	
	rather pointed at hands-on activities as more valuable	●	●			●
	the workshop facilitated critical reflection	●	●	●	●	



CONCLUSION

According to feedback provided by students after the experimental workshop run in Autumn 2023, equipping the studio with machines for testing physical models facilitated the development of integrated design processes. All groups of students recurred to the manual heliodon for refining their concepts. The planning of the activities did not success in exploiting the connection between analog and digital tools and the three steps seemed to be perceived as independent attempts rather than part of a one flow. Finally, the way activities have been planned and monitored, did not make it easy to understand the connection between the use of the digital script and the desire to follow active experimentation through the automated heliodon or other tools. Only two groups actually used the automated heliodon as third and last stage of the experimental workshop. This was apparently due to the fact that students perceived it as an unnecessary addition or too demanding considering the time pressure of the workshop. Interviews seemed to suggest that hands-on activities became so attractive that the digital tool ended up into a marginal activity. This clearly limited the intention of exploiting the potential of using digital tools as a computational tool for more qualitative analyses run through the use of hands-on activities.

This work represented the first attempt to more systematically analyze the potential of transforming the design studio in a laboratory for the development of integrated concepts. Analysis recurred to action research methods

and relied on the learning style inventory for mapping and understanding the learning process. During the workshop students could freely use machines for testing their physical models in relation to the sun but the way in which they took advantage of the lab seemed to be more determined by the climatic regions where they were asked to work. As it is natural, those concepts that had sun as main concern, took the largest benefit of the lab and methods proposed. In this case we could see clear benefits and students succussed in systematically improve their projects on the base of experimental analyses. Those groups that in their concept put the premises for a more detailed analysis about wind and form naturally perceived the workshop as a distraction and ended up not exploiting the activity and potential contribution for the development of the project. The tested experimental framework will be extended next year to define a new module about wind and form where the use of CFD tools will be combined with a water based streamline visualization tool for testing alternative morphological solutions and wind patterns.

ACKNOWLEDGEMENTS

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Integrating the Autism Spectrum Disorder Student in the Architectural Studio Classroom

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ABSTRACT: Higher education's student population is growing more diverse, incorporating neurodivergent individuals such as autism spectrum disorder (ASD) students. Factors contributing to this trend include heightened awareness of learning differences, improved diagnostic processes for ASD, implementing enhanced individualized learning plans, and adopting more effective special education practices. Architectural education is no exception. The creative and collaborative framework fostered in architectural education, particularly in programs based on problem-based learning (PBL) pedagogy, presents critical challenges and opportunities for ASD students. This work examines such challenges and opportunities by considering all stakeholders involved, i.e., ASD students, their colleagues, and instructors. Through literature review and interviews conducted at Aalborg University (an institution that uses PBL), this work maps ASD symptomatology, ASD students' needs, the opinion of a mentor of mentally impaired students, the challenges and ad-hoc strategies used overall in higher education in general and by architecture and design faculty. Additionally, the paper presents the results of a small experiment conducted with architecture students without ASD that exposed them to an aural environment that emulates ASD-related auditory hypersensitivity. The paper articulates the different collected information to reflect on PBL adequacy in teaching ASD in architecture programs, the effectiveness of current practices, the impact of environmental factors (e.g., space, aural environment) in this population, and outlines potential pedagogical strategies for this student population in an architectural studio setting.

KEYWORDS: Architectural Education, Problem-based Learning, Pedagogy, Autism Spectrum Disorder, Inclusivity and Diversity

INTRODUCTION

The student population in higher education is becoming increasingly diverse in terms of social and cultural backgrounds and ethnicity. This phenomenon also applies to students with cognitive impairments, such as those placed with autism spectrum disorder (ASD) (Mulder and Cashin 2014). ASD individuals are gaining admission to universities at higher rates due to several factors, including: (i) heightened awareness of learning differences at all educational levels, (ii) improved identification and diagnostic processes for ASD, (iii) enhanced individualized learning plans, and (iv) more effective special education practices (Gobbo and Shmulsky 2014). Architectural education is no exception to these circumstances, as the number of students with high-functioning ASD is increasing in its ranks. The creative and collaborative framework fostered in architectural education, particularly in programs or classes that utilize problem-based learning (PBL) pedagogy, presents both critical challenges and opportunities for high-functioning ASD students (de Groot and Smeets 2017).

This work explores the complex dilemmas experienced by ASD students, their colleagues, and instructors in a PBL environment of an architecture studio class. The main goal is to assess the adequacy of PBL to this student population and outline potential strategies and practices to better accommodate and integrate ASD students without prejudice to other students.

To that end, this work introduces PBL and ASD symptomatology through a literature review. By doing so, it examines the pedagogical challenges (e.g., social anxiety, impaired empathy, and difficulty in top-down creative processes) and opportunities (e.g., adapting to new challenges and motivation) of adopting PBL in teaching architectural studios that include ASD students. It also summarizes best practices for teaching this specific student population at the university level.

Furthermore, this study delves into practical insights through interviews with an ASD architecture student, a faculty member mentoring mentally impaired students, and urban design and architecture faculty. The interviews took place at the Department of Architecture, Design, and Media Technology (CREATE) at Aalborg University (AAU), where instructors use PBL pedagogy in their teaching activities.

The paper also presents the results of a small experiment conducted with architecture AAU students without ASD to enhance their perception of the difficulties faced by ASD students in a studio class context. The experience exposed the students to an aural environment that emulates ASD-related auditory hypersensitivity during group supervision. After the experience, the participants answered a survey that rated their ability to process information, think, and participate in the discussion. They were also asked to suggest changes in the environment (both physical and social) that would facilitate their engagement in the discussion.

Finally, based on the literature, the results of the experience mentioned above, and interviews and surveys conducted by the author, this work discusses the effectiveness of PBL in teaching ASD architecture students, deviations and alignments with best practices, as well as speculates on strategies for a better integration and studio teaching of ASD individuals.

1.0 BACKGROUND

1.1 Problem-based learning

PBL is a constructivist learner approach where students use self-regulated processes to acquire or construct new information (Slavin and Davis 2006). Initially used in medical education, PBL expanded to various fields, including engineering and architecture (Servant-Miklos 2020). Emphasizing cooperation, PBL employs a top-down approach, requiring students to tackle ill-structured problems by decomposing them into manageable subproblems. Collaborative group work is central to PBL, but its pedagogical framework is adaptable to individual work with minor differences, such as discussion being more dependent on dynamics with instructors. This paper refers to work in Aalborg University's architecture program, following the Aalborg model (Servant-Miklos 2020), primarily based on group work described below.

PBL starts with a pre-discussion phase, where student groups address a framed problem in a specific context. First, they try to form a tentative explanation and find relevant learning questions to guide their investigation. Afterwards, the students individually acquire new insights and then reconvene to share and critically assess the application of the new information in solving the problem. The group iterates this process until a satisfactory solution is found (de Groot and Smeets 2017). This process activates prior knowledge, facilitates the discovery and acquisition of new information, and involves active processing (Schmidt et al. 2007). Teacher guidance facilitates, mediates, and provides a scaffold to build knowledge and skills. In sum, PBL is a (i) constructive, (ii) self-directed, (iii) collaborative, and (iv) contextual learning process.

PBL and project work in typical architecture studio courses share significant common ground. In fact, the distinction between PBL and problem-oriented project work, common in architecture, is hazy and subject to interesting debates (Servant-Miklos 2020). Since those debates are not the focus of this work, the author recommends Servant-Miklos (2020) to learn more about the minor differences between the two pedagogical approaches. The main point is that PBL is easily adopted (partially or fully consciously) in architectural studio/project courses, as studio instruction is based on structuring students' activities in solving specific open-ended problems (Alcock, Fisher, and Zmuda 2018).

Some see the self-directed learning process of PBL and its "minimal" guidance as a limitation (Kirschner, Sweller, and Clark 2006). Nevertheless, Schmidt et al. (2007) argue that the constructive principle of scaffolding does not mean that guidance is minimal; it just implements it differently as instructor guidance in formulating the problem, along with regular and consistent supervision, offers students a "scaffold," i.e., a structure that enables the acquisition of new information, knowledge, and skills (Schmidt et al. 2007).

The positive aspects of PBL include: (i) enhanced study motivation for studying and interest in the subject matter, (ii) higher satisfaction with the relationship between all stakeholders, (iii) and with applying knowledge in practice, (iv) improvement of practical, scientific, social and critical thinking skills (Loyens, Kirschner, and Paas 2012), (v) longer term retention of learned material (Schmidt et al. 2012), (vi) improved teamwork and communication skills (Fang 2012), and (vii) faster graduation and lower student dropout rates (Schmidt, Cohen-Schotanus, and Arends 2009).

1.2. Autism spectrum disorder symptomatology

This work focuses on highly functional ASD, as they are the most likely to take a college degree. Highly functional ASD students refer to those who can socialize (to a certain extent), communicate, and are typically considered efficient in handling specific tasks, such as the case of most Aspergers individuals. ASD individuals have severe impairments beyond the social challenges commonly found in this population (Neihart 1999). The following overarching models (Gobbo and Shmulsky 2014) summarize ASD symptomatology:

Mindblindness – or impaired empathy, is the lack of perspective of other people's mental and emotional states and an inability to respond appropriately, hindering ASD individuals from having normal social relationships (Baron-Cohen, Knickmeyer, and Belmonte 2005). Beardon et al. (2009) reported that around 40% of students with ASD express group work, social interaction, and communication with their peers as their biggest challenges. Knott and Taylor (2014) also show that ASD students often see their peers as less conscientious. Such aspects often lead them to execute most of the work by themselves.

Weak central coherence (WCC) – is a type of cognitive disorder that involves overlooking the "big picture" towards a more detail-centered way of processing. ASD individuals have difficulties processing overarching ideas and typically accumulate knowledge incrementally (Happé 2005). WCC hampers such individuals to tackle top-down processes that require inference, synthesis, and argumentation. The reduced generalization hypothesis (RGH) (Plaisted 2001) argues that the reduced ability to process similarity among ASD individuals hampers their ability to generalize information. WCC also explains some of the strengths associated with ASD individuals, including the ease in collecting data, conducting focused analysis, and performing tasks that require accuracy and attention to detail. ASD individuals prefer bottom-up than top-down approaches.

Execution functions – refers to the mental skills that enable individuals to start, stop, and persist at cognitive, emotional, and behavioral goals. They keep individuals motivated and engaged and are essential in planning and monitoring the progress of resolving a problem or fulfilling goals. Execution functions also enable individuals to do conceptual and attentional shifting. ASD individuals struggle with essential execution functions, particularly planning and cognitive flexibility that enables conceptual and attentional shifting. Thus, ASD students often have difficulties with transitions in academic content, tasks, and environment. Unexpected or swift changes can trigger high levels of stress, depression, and anxiety (de Groot and Smeets 2017). Thus, prioritizing, organizing, managing time, initiating and aborting working on projects, quickly shifting between different sources of information or subjects, and planning, especially long-range, are challenging to ASD students.

1.3. Problem-based learning and autism spectrum disorder students

By relating ASD symptomatology to PBL's main constructivist ideas, it is possible to identify several points where the PBL teaching approaches might be aligned or at odds with the characteristics of highly functional ASD individuals.

A central aspect of PBL is collaborative learning, i.e., students cooperate to address a problem (e.g design brief). The aim is that students acquire new information, assimilate, and apply new knowledge by learning and collaborating with their peers. However, mindblindness hampers ASD individuals from socializing and cooperating. Communication deficits also hamper their ability to engage in collaborative learning tasks. Thus, collaborative learning poses a significant challenge to ASD students. Hence, it is necessary to devise strategies to facilitate and engage ASD students in collaboration tasks.

Contextual learning, i.e., acquiring and generalizing knowledge from a specific problem, is central to PBL. Nevertheless, due to WCC and RGH, ASD students have difficulties abstracting, generalizing, and applying knowledge or skills outside the context from which they acquired it. Therefore, this PBL aspect challenges such students and instructors must be aware of it and act accordingly.

PBL often favors top-down approaches (e.g., decomposing problems into easier-to-solve subproblems). Top-down problem-solving requires vital execution functions, such as structuring the problem, prioritizing, planning, initiating/aborting tasks, and articulating different parts of the problem in terms of scope and content. ASD individuals struggle with transitioning due to their limited ability in execution functions (de Groot and Smeets 2017). Hence, ASD students find transitioning in studio work burdensome, heightening anxiety and confusion. Thus, the top-down PBL aspect conflicts with the skill set of ASD individuals.

Given the above, it is reasonable to consider PBL inadequate for ASD individuals. Literature reports that higher ASD symptomatology correlates with increased difficulties in group work, communication, focus shifting, and contextual learning (de Groot and Smeets 2017; Gobbo and Shmulsky 2014). However, ASD students face similar difficulties with traditional pedagogical frameworks (Gobbo and Shmulsky 2014; Knott and Taylor 2014). Contrary to the notion that PBL is unsuitable for ASD individuals, Groot and Smeet (2017) argue that different aspects of PBL are well-suited for them, as follows:

- Although PBL often uses top-down approaches, it also supports collecting information and uses it to construct a whole. These features can provide solid scaffolding to accommodate top-down processing and build a stronger central coherence.

- PBL often delegates to students the tasks of selecting the topic of interest and formulating the problem. Highly functional ASD individuals usually have an abiding interest in specific subjects, which makes them seen by their peers as experts in certain topics. This helps socialization, group work, and motivation for ASD students.

- Although group work is challenging for ASD students, PBL groups are often small, which eases their interaction with peers, fostering familiarity. This encourages active participation in discussions, preventing passivity. Small group settings also provide a secure environment for ASD individuals who benefit from vocalizing thoughts to structure them.

- Commonly, PBL has a strict schedule, with proximal deadlines for projects and exams. Additionally, courses are typically given sequentially in PBL curricula, i.e., one at a time. These features can smooth the ASD difficulties related to some executive functions, such as planning, prioritizing, starting/stopping tasks, and transitioning between learning tasks.

- Although WCC hinders contextual learning, it presents some advantages. First, it often offers clear problems, alleviating frustration and stress for ASD individuals dealing with ambiguity (Gobbo and Shmulsky, 2014). Secondly, PBL facilitates differentiated teaching (Rubenstein et al. 2013), enabling gradual adjustments in context, content, learning issues, and goals, thus providing valuable scaffolding for ASD students. Thirdly, highly functional ASD individuals find motivation in the challenges and practical nature of PBL-formulated problems.

Additionally, the study shows that the Autism Quotient score (AQ-score) is a good predictor of experiencing problems and benefits in PBL. Higher the AQ-score, higher the likelihood for ASD students to experience more difficulties. However, the study also demonstrated that the AQ-score is not a good predictor for student performance. The results showed that ASD students perform well in a PBL environment regardless of their perceived difficulties and benefits. The authors present two main reasons for these findings:

- Perceived problems are experiences and not objective measures. Thus, students reporting group work difficulties don't necessarily perform poorly; it may be a perception rather than a genuine issue. However, dismissing this feeling is unwise, as ASD students are more prone to stress, depression, and anxiety (Sterling et al. 2008).

- The study indicates ASD students accommodate well to PBL challenges. Anecdotal evidence reveals ASD symptoms affect the early years more than the upper years. Additionally, a challenging learning environment supports their growth. Although desirable difficulties might cause discomfort, they also provide positive outcomes, such as grades or the feeling of overcoming limitations. Thus, exposing ASD students to certain challenges prepares them for a post-educational setting.

1.4. Current best practices in supporting autism spectrum disorder students in higher education

PBL desirable challenges support academic growth for ASD individuals but may cause stress and anxiety (de Groot and Smeets, 2017). Mitigating stress causes and providing structure in a self-regulated learning approach is crucial for both ASD and TD students.

Gobbo and Shmulsky (2014) surveyed faculty in a college catering to students with learning impairments, including ASD. While not specifically centered on architectural studios, their broad recommendations are applicable to education in architecture. The study proposes two groups of best practices, as follows:

Provide structure: A way to provide structure is to reduce ambiguity, introduce predictability, and minimize change or abrupt transitions in teaching. For example, previewing the supervision and using routines reduces confusion and facilitates a smoother transition between topics and tasks. These strategies can mitigate difficulties related to executive functions. Using clear and concise language also helps ASD students with WCC-related difficulties. Additionally, providing opportunities for ASD students to exercise their strengths and pursue their interests fosters interest, social integration, motivation, and self-esteem.

Reduce Anxiety: Instructors must identify potential stressors during teaching, staying attuned to students' emotional states, especially noting early signs of agitation. Addressing agitation promptly is crucial, with strategies like adjusting the discussion pace or promoting breaks to reduce sensory stimuli. Engaging in one-on-one discussions with ASD students about potential discomfort aids in quick detection and intervention. Explicitly stating behavioral expectations can assist with mindblindness-related challenges, fostering discussions on individual differences in experience, expression, and learning styles at the course's outset.

The suggested instructional strategies are heuristics derived from experienced instructors with ASD students. These approaches extend beyond ASD individuals and can also benefit TD students facing similar challenges. Therefore, these teaching strategies prove valuable for the entire student population.

2.0 METHODS

To assess the practice of teaching ASD architecture students in a PBL context, the investigation departed from the literature review by adopting the following approaches and tasks described below.

Interviews: The author held interviews with an AAU ASD student and with an AAU teacher in architecture who is a mentor to students with mental disorders. The interview with an ASD student aimed to identify the difficulties, needs, and benefits experienced by such students in a PBL setting, as well as their coping strategies. The interview with the faculty mentor aimed to provide insight into the role of the mentor in supporting students with mental impairments in a university that uses PBL as its main pedagogical framework. Although their anecdotal nature, both interviews provide a valuable perspective of an instructor/mentor and an ASD student in an architecture program based on PBL.

Questionnaire/Survey: This task consisted of a questionnaire that aimed to survey the pedagogical strategies used by the current faculty of the architecture, urban, and industrial design sections in CREATE at AAU in addressing the inclusion of ASD students in studio classes based on PBL.

Studio supervision experiment: This experiment simulated auditory hypersensitivity, an ASD symptom, among TD students of the Architecture master's program at AAU. They experienced a sound clip emulating how ASD individuals perceive the aural environment during a project group supervision. Exposed to auditory overstimulation for approximately 2 minutes, students engaged in discussion or presented their work. The sound clip was based on videos from the Interacting with Autism research project (Harris and Kinder 2015). Following the experience, students anonymously rated their ability to process information, think, and participate using a Likert scale. They also shared feelings and suggested actions to enhance supervision accessibility. The goal was to increase awareness and empathy for ASD colleagues while involving students in creating a more inclusive environment by proposing changes in supervision structure and the physical and social environment.

3.0 RESULTS

3.1. Interview to a mentor of students with mental disabilities at CREATE (AAU)

Due to restrictions of space the following summarizes the outcome of this interview. The interview showed the relevance of the mentorship program in providing structure to students with mental disabilities, including ASD ones. The interview shows that trust is critical in the relationship between mentor and student, as the mentor is often seen by ASD students as a figure of authority that provides safety and insight. Through open conversations the mentor guide ASD students to better understand their limitations and cope with them.

The mentor provides structure by helping students developing a detailed study plan with proximal deadlines for different types of tasks. This gives a clearer path for the students and, therefore, reduces their anxiety, stress, and helps them to cope with transitioning in their academic life. Nevertheless, such study plans can only be effective if the course instructors facilitate a detailed and well-structured course plan beforehand. Thus, a good collaboration between instructors and mentors is paramount for successfully support ASD students. Another way to provide structure is to develop certain study and behavioral patterns (e.g., request pauses in long lectures or work sessions), as ASD students gradually adjust to a new situation through repetition.

The mentor also works with the students in developing their self-awareness about their academic strengths and difficulties and to clearly communicate them to their peers and instructors. This facilitates the social integration of such students, putting into a better use their potential. It also helps them to improve their self-esteem and motivation. Finally, the mentor referred that is important for the students to be open about their condition, both with their peers and instructors, in order to build an environment characterized by empathy and trust. Knowing the condition of ASD students is also vital for the instructor to address their needs while balancing the needs of others. In sum, trust is essential for integrating the ASD student in a PBL environment. Moreover, the work of mentors is critical, as it provides continuous and consistent support for the accommodation of such students to PBL and other environmental challenges.

3.2. Interview to a student with autism spectrum condition at CREATE (AAU)

The student is diagnosed with attention deficit disorder (ADD) and ASD. The student openly talked about difficulties regarding group supervision in architectural studio, and studio exam, which is typically a group oral exam in CREATE. The following summarizes this interview.

In architectural studio's group supervision, the student highlighted some communication challenges. The feeling of sometimes not having a voice was recurrently mentioned. This happens because the student needs time to carefully ponder every discussion aspect (a WCC trait), while the other members quickly move between topics. Additionally, the student appreciates when the instructor directly promotes the student's participation in group discussions, as social anxiety often prevents the student to pose questions. Often, the student is annoyed if the discussion lingers in a subject that is not interesting or already fully understood by the student by not the rest of the group. Despite the challenges, the student acknowledges that being gradually exposed to group work helps to cope with social anxiety and create social bonds.

Finally, regarding project examination, the student mentioned an increasement of anxiety with the presence of several people and if the jury is composed of people the student has never met before. To better cope with the exam environment, the student often requests special dispensations that might include the presence of a close family member and more time to understand a question and formulate an appropriate answer or even conducting part of the exam alone.

3.3. Questionnaire about teaching students with autism spectrum condition at CREATE (AAU)

Nine CREATE instructors from Urban Design, Architecture, and Industrial Design responded to a questionnaire with the goal was to get an overview of the teaching strategies that address ASD students in studio supervision and project exams. If the respondents were unaware that they instructed an ASD student, they needed to imagine such a situation.

The studio related questions addressed the inclusiveness of ASD students. Regarding promoting their participation, most teachers think that methods used to engage more introverted students are applicable, such as: (i) directly asking questions, while being attentive to their well-being, (ii) discuss the communication methods used by the group, and (iii) directly ask the ASD student opinion often. Some additional strategies include discussing with ASD students about the supervision structure and helping the group develop rules for supervision that address ASD individuals' needs. Strategies for an equitable distribution of tasks mostly rely on helping the students develop a work plan and an agreement about task distribution, which is already a typical PBL strategy.

The responses were more diverse regarding fostering creativity. Some believe there is no need to address this, showing their unawareness that WCC and RGH hamper creativity of ASD students in typical top-down PBL workflows. Others were vague in describing some strategies such as "active listening," "externalize ideas on paper," and the common PBL strategy of shifting tasks between individuals, which might be at odds with the difficulty that ASD individuals have in transitioning.

For design studio exams, ensuring a comfortable yet challenging environment is unanimous among respondents. Clarity about the exam format, outline, and time schedule is deemed essential. The variation lies in the formality of communication, with preferences ranging from conversational to detailed explanations before the exam. Some respondents acknowledge the WCC and executive function challenges of ASD students, emphasizing the need for clear and unambiguous language in questions. They suggest allowing students to ask for question reformulation,

extra processing time, and consider these strategies sufficient for managing exam-related stress and anxiety. Some respondents propose additional measures like individual supervision before the exam, a 5-minute break during the exam, calming down the student if agitation arises, and offering the opportunity to visit the exam room beforehand, which can help in transitioning. Finally, examiners are advised to maintain a calm.

3.4. Studio supervision experiment

Architectural studios in AAU are loud and lively open spaces like most studios in other programs, exposing ASD students to a high risk of sensory overload through their auditory hypersensitivity. As previously mentioned, this experiment exposed several TD students to auditory hypersensitivity for 2 minutes using a sound clip listened through headphones during supervision. The experiment involved 20 participants from the first semester in AAU's Master of Science in architecture. Figure 1 shows the results of the questionnaire that the participants filled after the experiment. It summarizes the ability of students to conduct essential tasks in a project supervision session including engage/participate, concentrate, reason, and follow/understand the discussion. Students rated their ability to perform such actions during supervision using a 7-step Likert scale that goes ranges from -3 (very difficult), 0 (neutral), to 3 (very easy).

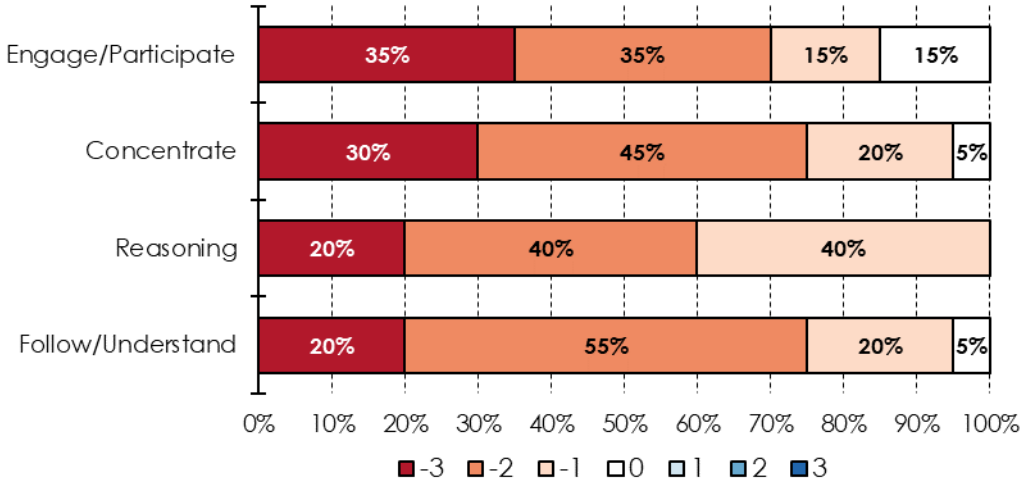


Figure 1: Results of the survey that assess the experience of TD students when exposed to auditory overload as commonly experienced by ASD students. Source: (Santos 2024)

Figure 1 shows that most participants experienced difficulties in all typical supervision tasks (85%-100%). The most divisive task was to engage/participate in the discussion as 70% reported that was very difficult (-3) or difficult (-2) while 30% indicated that they had a slight or neutral difficulty level. This can be explained by some participants being used to loud environments that require constant social interaction, e.g., some students work or worked in bars or restaurants. Regarding concentration, 75% of the participants reported that it was difficult (-3 and -2). Follow and understanding the supervision score the highest in category -1 (difficult) which is concerning as discussion consistency and the comprehension of the discussed concepts, and their enchainment, is central in architectural studio supervision. Finally, all students struggled in reasoning during supervision. Such overall difficulty is linked to the hardships in concentration and understanding. Although reasoning is essential to react and generate alternative design strategies/solutions, it is less concerning than the challenges in following/understanding as it requires maturation and partially happens after the supervision.

When asked about what their group colleagues could do to facilitate the participation in supervision, participants replied that using body cues such as gestures to grasp the attention, directly address the person that is experiencing a sensory overload, and use other communication tools such as drawing and writing. Students provided similar responses when the question focus on the instructor such providing supervision but adding and stressing the importance of the instructor use clear and straightforward language and directly. Point-out the part of the drawing or model being discussed, draw diagrams about the discussion topic, speak slowly, emphasize (by repeating) the main points and take-aways of the discussion, and breaking long supervision sessions in smaller ones with breaks were other useful suggestions.

Regarding potential changes to the physical environment students stressed that open spaces are not adequate when exposed to such auditory overload. Suggestions include moving to a quieter preferable enclosed space or shield the group space from noise using furniture, sound absorption materials, and movable partitions. One participant suggested asynchronous supervision with other supervisions to mitigate confusion and noise levels.

CONCLUSION

This paper discussed the challenges and opportunities of teaching ASD architecture students within a PBL context by examining the literature and assessing the current practice of an architecture and urban design program in a PBL university, AAU.

Despite the difficulties perceived by ASD students, PBL poses desirable challenges that allow gradual accommodation towards academic success. Additionally, PBL's practical nature addresses some limitations related

to executive functions, as PBL's contextual nature reduces ambiguity and progressively prepares ASD students for a post-academic life. The interview with the ASD student and mentor showed that PBL can bring the rewarding feeling of overcoming obstacles. PBL can help build self-esteem and tackle some mindblindness limitations. Additionally, the typical structure of PBL programs of sequential classes and proximal deadlines can help ASD individuals manage their time and expectations. Nevertheless, PBL's top-down and transitioning nature poses challenges related to WCC/RGH that should be addressed using some of the techniques discussed below.

PBL's desirable challenges need to be presented in ways that mitigate stress and anxiety in ASD students and foster a pleasant learning experience for all students. To that end, some typical PBL strategies, such as helping project groups establish clear rules for work distribution, communication, and learning outcomes, are helpful. Other learning strategies more targeted towards ASD students also have the potential to benefit the other students, such as promoting regular breaks in supervision, providing a supervision plan beforehand to accommodate transitioning, avoiding using ambiguous language, smoothly and consistently shifting topics in a discussion, and keep consistent supervision patterns and styles. Another critical point is building an environment of trust between ASD students, their peers, and instructors. To generate trust, it is essential that ASD students communicate their condition and that their peers and instructors should be available and empathic towards their needs. Both the literature and the interviews highlight that trust and openness are critical for the personal, social, and academic growth of ASD students. Another vital strategy is to help them know and communicate their skills and limitations.

Although studio instructors are not formally trained to teach ASD students and often are not aware of their presence, they have a good intuition on how to act, integrate, and address the needs of such students. Most of the strategies mentioned in the questionnaire align with current practices reported in the literature, showing that common PBL strategies suit both TD and ASD individuals. However, some of the faculty survey responses are poorly systematized, indicating a lack of an overview on how to integrate the ASD student and balance the different psychological needs of a diverse studio environment. Furthermore, the lack of awareness that the number of ASD students is increasing prevents instructors from acting more conscientiously. Thus, consistently promoting public sensibilization actions and small workshops on these matters could improve awareness and equip faculty to address mental impairments in studio supervision and exams. Additionally, this work suggests that knowing more about ASD symptomatology helps adjust learning activities in a way that can benefit all students.

A mentorship program for mentally impaired students is also crucial in providing support, structure, and confidence to ASD students. The interviews with the mentor and ASD student indicate that students gradually become more capable of socializing tasks and structuring and managing their academic responsibilities.

From the studio supervision experiment, it is possible to verify, once more, the need to provide a clear structure for the supervision in terms of discussion content and communication procedures. Exposure to sensory overload in a studio group supervision causes stress and exhaustion that hampers the ability to engage/participate, concentrate, reason, and follow/understand the supervision discussion. Therefore, frequently emphasizing essential aspects of the supervision by using body language and drawings, swiftly acting upon signals of agitation, such as promoting a short break or modulating the supervision pace and tone (e.g., structuring the desk critique into different periods, such as initial discussion, break, a quick exercise, and summary discussion), can effectively help reduce anxiety levels and grasp the attention of both ASD and TD students. It was also clear that a loud and lively open space is adverse to ASD students. Thus, the author recommends, whenever possible, supervising groups with ASD students in separate classrooms or rearranging the space of the specific group to mitigate the exposure of sensory stimuli to ASD students.

Finally, this study briefly addresses a complex problem that demands a multidisciplinary approach. Considering the limited size of experiment participants, the interviews, and the questionnaires conducted in this work, it can only provide anecdotal evidence. Nevertheless, this study offers relevant insights into a topic seldom addressed in literature. Future work would expand the number of participants in interviews, questionnaires, and experiments and devise new experiments to assess the proposed strategies more systematically.

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Bridging Analog and Digital Realms: Fostering Sustainable Design Innovation Through Integrated Teaching Techniques

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ABSTRACT: Digital simulation tools for environmental performance analysis are widely employed in architectural practices around the world. For this reason, teaching students how to use those tools is increasingly becoming an important part of the architect's education and future employability. However, in architectural design, digital tools, providing fixed numerical outputs, have the potential to lead to design fixations, limiting the students' capacity for innovative thinking by restricting their design actions. This study suggests that digital tools can be used not only as tools for complex computational analysis in the architect's practice but also as pedagogical tools facilitating the integration of numerical simulation outputs in holistic design processes, enhancing the learner's experience. The study further infers that one method to accomplish this is by incorporating digital tools into hands-on activities and experiments. To test the hypothesis, we designed and tested an experimental workshop. Action research was chosen as a methodology, enabling the researchers to participate in ongoing situations, influencing the events while simultaneously being able to measure the impact of their interventions. All activities followed Kolb's Experiential Learning Theory and Schenck & Cruickshank's Co-constructed Developmental Teaching Theory. A set of digital and analog tools for simulating environmental performance was incorporated into the teaching and learning activities of the workshop. The juxtaposition of the different simulation capabilities of those tools aimed to provoke students to reflect and build a holistic understanding of the subtleties of simulation results. This article is the conclusion of the first workshop and summarizes the attempt to incorporate those tools into hands-on activities and experiments, encouraging students to test the boundaries of their design solutions on both quantitative and qualitative basis. The main discussion points are the methodology and methods employed in the first workshop and the agenda for improving the protocols for the next planned workshop.

KEYWORDS: Analog tools, architecture education, bioclimatic design, computational analysis, digital tools

INTRODUCTION

The context of this study revolves around sustainable architecture, environmental and bioclimatic design, and pedagogy. The study addresses the changing demands of the architectural profession in the face of technological and climate change and stresses what aspects of introducing different tools for environmental performance to architecture students require heightened attention to avoid design fixations and limiting their creativity. The main focus is on the pedagogical potential and limitations of analog tools, such as heliodons and wind tunnels, and digital tools for parametric modeling and environmental analysis, such as Rhinoceros 5 with Grasshopper and Ladybug.

To a large extent, designing sustainably has to do with energy conservation, maintaining a balance between capital cost and long-term asset value, and, in general, minimizing overall impact (Edwards 2010, 1). Different approaches and strategies can be employed to accomplish such results. Some of the most common approaches are building performance analysis, life-cycle assessment, and integrated energy design. However, a truly sustainable design is also about creating healthy spaces, aesthetically pleasing for the user, as well as economically viable while sensitive to the present social needs.

The complexity of the problems posed by our rapidly changing environments (natural, socio-cultural, and economic environments) and our need to constantly adapt and improve call for a holistic approach to design. Often, education tends to specialize and train young professionals to make design choices supported by technological means, "not realizing that specialization precludes comprehensive thinking" (Fuller & Snyder 2019, 13).

While it is certain that students benefit from the extensive use of digital simulation tools to run complex computational analyses and facilitate the integration of their results in architectural design processes, it also produces a general concern regarding the reduction of the standard of actual architectural qualities in the students' projects. That concern arises because digital simulation tools provide numerical outputs that can easily be used as justification for design choices during defenses and presentations. Experienced professionals can usually interpret the subtleties of simulation output and results and understand the implications an error gap could have. However, novice users and students, if not prepared to take a holistic approach to design, often overemphasize those outputs, which can result in limited design actions, paralyzing the students' creativity.
The project's goal is to investigate the potential to use digital tools not only as tools for mere computational analysis that will improve the students' employability after they complete their degrees but also as pedagogical tools that have the potential to enhance the learner's experience.

The main interest falls on the role of tools when it comes to fostering creativity and facilitating the development of innovative solutions. The main question is how tools for environmental control can encourage students to develop environmental imagination without reducing their environmental responsibility to a numerical answer.

Furthermore, the work looks at concepts such as Design Fixations (Jansson & Smith 1991), or the inability to creative problem solving and innovation because of preconceived knowledge and prejudice, Non-neutrality of Tools (Heidegger et al. 2019, 355-361), or the tool's role in education and personal development, and overall barriers to Deep Learning (M. Fullan, M. Langworthy 2014), where students are driven by curiosity and internal desire to learn, usually going beyond the requirements of the assessment criteria or even beyond the curriculum.

1.0 BACKGROUND

Although digital simulation tools for building performance analysis allow architects and engineers to simulate and explore the environmental and energy performance of buildings in more detail than ever before, with less effort, time, and almost no related cost, they may have a negative impact on the learning outcomes of architectural students leading to Design Fixations, limiting the students' capacity for innovative thinking. There are three reasons we have identified why this may be so, and they are the numerical nature of simulation outputs, the planned learning outcomes of courses on simulation tools part of design programs if not integrated into holistic design processes, and evaluation strategies that focus on formative assessment methods and do not support experiment and risk-taking.

1.1 Numerical output

Digital simulation tools provide numerical outputs that can easily be used as design drivers during the design process or as justification for design choices during defenses and presentations. However, if the accent is moved to the purely quantitative dimension without inviting students to a more critical analysis, reflection, and holistic approach, then the risk of limited qualitative value arises.

If the goal is to educate young professionals on how to design sustainable buildings, educators must take a holistic approach. As Brian Edwards concludes in his "Rough Guide to Sustainability" if a design does not reflect aspects of the social, cultural, or economic conditions, "energy-conscious design by itself will be of little value" (Edwards 2010, 1).

1.2 Learning outcomes

Courses on simulation tools often align their learning outcomes with the transfer of knowledge and the attainment of particular skills, mastering the particular tool. Those skills and knowledge are tangible and often might increase the students' employability once they complete their degree. However, when simulations are used in the design process, it is essential to balance the quantitative analyses with qualitative analyses.
According to Tavares,

> social, legal and technical demands are progressively reducing the architect's freedom when it comes to decision making and often architectural decisions are no longer directly linked to architectural knowledge (Tavares et al. 2016).

Moreover, to comply with a series of increasingly stringent environmental requirements, designers often tend to rely on predetermined solutions. As such, the need to lower the environmental impact of the built environment on a quantitative basis might create the dual challenge of narrowing the focus of a design process while limiting the development of creative and innovative solutions.

If architectural education starts focusing only on the achievement of a series of static learning outcomes, equipping the students with competencies that they can easily spend in common practices based on the attainment of explicit knowledge, which can be tested, assessed, and rewarded, this might mislead students that there are univocal effective design configurations (Soares 2016, 169). In other words, teaching models structured in this way could lead to "design fixations" - the inability to creative problem solving and innovation because of preconceived knowledge and prejudice. This is why it is crucial to stress the importance of balancing the quantitative and qualitative dimensions once again when it comes to design.

1.3 Evaluation strategies

Evaluation strategies that conclude with formative assessment in the design courses might lead students to cautious and formulaic approaches to design, where priority falls on producing safe, predictable outcomes that the students believe will earn them higher grades.

One of the key concerns is that grades can stagnate the design process by encouraging students to focus solely on achieving high scores rather than exploring innovative and creative solutions. The fear of failure or a lower grade can deter students from taking risks and experimenting with new ideas.

The overemphasis on grades can also result in design fixations, as mentioned before, where students repeatedly use solutions that have worked in the past. These fixations occur because students often subconsciously recognize that specific approaches consistently yield higher grades. Consequently, they become reluctant to deviate from these proven methods, resulting in a lack of diversity and originality in their work.

Grades can inadvertently limit students' capacity for innovation by creating a risk-averse learning environment. In design disciplines, innovation thrives when students are encouraged to push boundaries, experiment, and challenge conventional norms. However, when assessment strategies are overly focused on the end product and its conformity to predefined criteria, students may become less inclined to explore unconventional ideas and opt for safe, conventional solutions. In the design disciplines, in order to avoid design fixations due to the evaluation strategies, it is essential that those strategies support experimentation and have methods to support students to take risks without the fear of failing.

2.0 HYPOTHESIS

Our hypothesis is that one way to encourage students to build a more holistic approach to architecture, instead of focusing on attaining purely technical skills, is to incorporate the use of computational tools for environmental performance analysis in hands-on activities and experiments. Furthermore, encouraging students to combine both analog and digital tools, where the output of one feeds further investigation with the other, could have the potential to facilitate a better understanding of the subtleties of simulation results and outputs and lead to a state of Deep Learning.

3.0 THEORETICAL FRAMEWORK

To test the hypothesis, an experimental workshop was designed and tested in the Climate and Built Form course, part of the MSc in Sustainable Architecture at the Norwegian University of Science and Technology - NTNU. The workshop was designed within the theoretical framework of Action research (Cohen et al. 2018). The cyclical structure of Action Research entails systematic intervention based on the simultaneous process of taking action and doing research linked together by critical reflection (Somekh 2006). This allowed us as researchers to actively participate in the teaching and learning activities and to engage in and influence ongoing situations without compromising the data collection protocols or the protocols for measuring the impact of our interventions.

The workshop comprised three cycles, each incorporating different tools, alternating between digital and analog ones. Each cycle was structured following Kolb's Experiential Learning Theory (Kolb 2021) and Schenck and Cruickshank's Co-constructed Developmental Teaching Theory (Schenck & Cruickshank 2014). This means that each cycle had embedded reflection, conceptualization, and experimentation phases, following Kolb's Learning Cycle (Fig. 1.1) as a basis. Furthermore, the activities built upon the output and results of the previous ones, creating a continuous Learning Spiral (Fig. 1.2) where the next inquiry always increased in complexity.

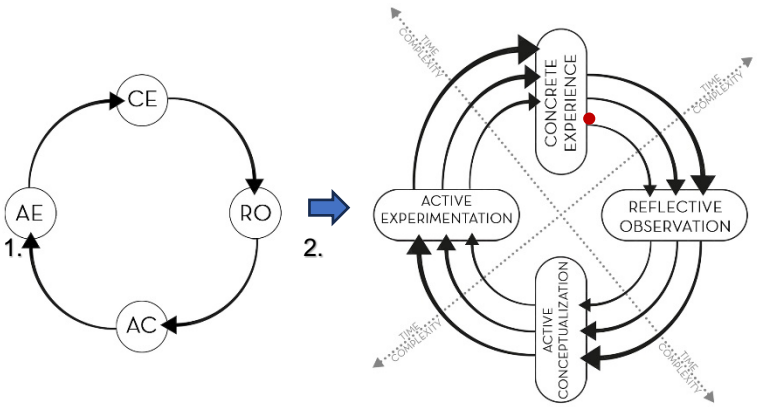


Figure 1: 1. Kolb's Learning Cycle; 2. Schenck and Cruickshank's Co-constructed Developmental Teaching Theory. Source: (Assembled by the authors 2023)

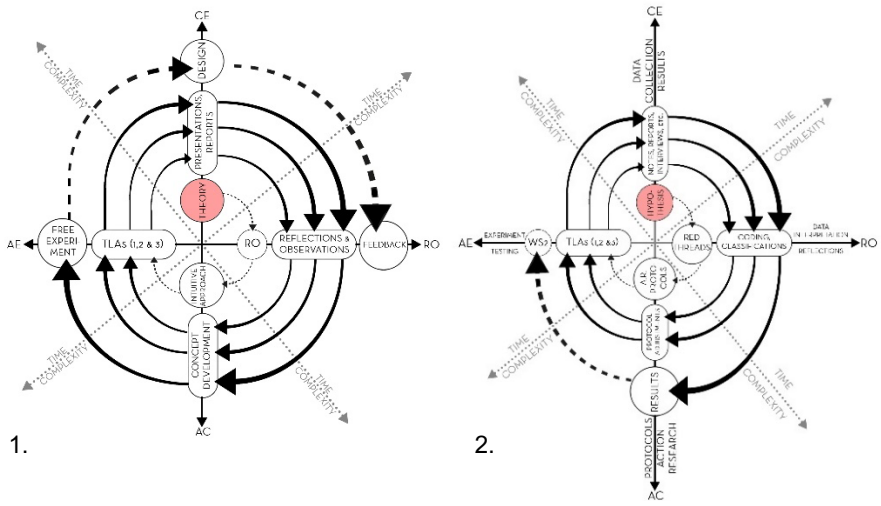


Figure 2: 1. Workshop activities' scheme; 2. Research design structure scheme. Source: (Assembled by the authors 2023)

In order to structure the protocols for the inquiry, we developed a double-loop Action Research design, applying the same didactics we followed for the workshop activities (Fig. 2.1) on the research structure itself (Fig. 2.2).

4.0 METHODOLOGY: EXPERIMENTAL WORKSHOP DESIGN

Based on the background material presented, we suggest that there are three potential reasons leading to Design Fixations limiting architecture students' capacity for innovation and creativity. We further suggest a potential method to avoid this by implementing the use of computational tools for environmental performance analysis in hands-on activities and experiments. To test this, we set up a three-week-long experimental workshop incorporating teaching and learning activities aiming to overcome those barriers to Deep Learning. The workshop was tested within the "Climate and Built Form" course at the Norwegian University of Science and Technology - NTNU. All the activities were designed to support the development of the students' semester design projects within the module of the course, focusing on the relationship between sun and form, encouraging the students to explore different solar responsive design solutions. The study investigated the impact of the teaching and learning activities based on observations, the learning outcomes, and the students' feedback. Protocols were designed for data collection and interpretation. The goal of the workshop was to strike a balance between structured experimental procedures with various simulation tools, enabling the students to improve their designs based on evidence in a systematic manner while making sure that they also have the opportunity to reflect on the simulation outputs, how the different simulation tools replicate the real-world climatic phenomena and what factors might influence those outputs.

4.1 Tasks

The main task for the students was to design a prefabricated climate-adaptive shelter for post-disaster recovery. The students were split into five groups, and each group was presented with a different climatic context to work with. The students had to take into consideration both quantitative and qualitative aspects of architectural design, from spatial and functional requirements and environmental and energy performance to socio-culturally sensible construction methods and infrastructure.

There were three cycles incorporating different teaching and learning activities, each including different simulation tools, alternating between digital and analog ones. Each cycle took approximately a week.

The first week of the workshop included activities with a conceptually clear heliodon paired with hands-on activities. The students were asked to form three individual research questions in regard to the relationship between sun and form in the context of their own designs and answer them by performing experiments with the heliodon. The hands-on activities entailed model-making and prototyping.

During the second cycle in the second week of the workshop, the students were introduced to Grasshopper, a parametric modeling tool, and Ladybug, an environmental analysis plugin, and given an exercise following a pre-written script for form optimization and orientation based on the Sol-air approach (Olgyay 2015). The exercise was intentionally using a hypothetical box in the respective climatic conditions of each group to avoid the limiting effect direct numerical outputs could have on the design process and to encourage the students to reflect on their findings rather than directly applying them in their designs. We wanted to avoid specific software-generated numerical outputs, undermining the students' critical thinking abilities and influencing their design choices from the outset. The hands-on activities in this cycle entailed prototyping different solar design solutions based on the reflections from the exercise and testing them in both the conceptually clear heliodon and the software.

During the third and last week of the workshop, the teaching and learning activities were introduced through the use of an automated heliodon equipped with micro-cameras for solar access analysis. In this final week, the students were not given any specific task but were encouraged to make use of the tool and document their findings and how the process of using the tool might have influenced their design choices.

At the end of each week, the students were asked to present their findings in front of teachers and peers, and a feedback session concluded each cycle.

4.2 Experimental conditions

Before the start of the workshop and after the theoretical part of the course, the students were asked to design a concept based on an entirely intuitive basis without the help of any simulation tools, analog or digital. This was done to encourage students to use their creativity without any constraints or input other than their critical thinking and imagination, which might influence their design choices. Furthermore, the preliminary design concepts they developed served as the test materials for the workshop activities. The workshop activities were not separately graded. However, since the workshop was incorporated within the regular activities of the “Climate and Built Form” course, part of the MSc in Sustainable Architecture at [institution redacted for review purposes], the final designs they worked to improve through the workshop activities resulted in their semester projects, which were assessed and graded at the end of the course. The workshop was structured in this manner in order to avoid overburdening the students with extra tasks they might perceive as a waste of time or distraction.

4.3 Experimental procedure and protocols

The workshop consisted of three cycles structured following Kolb’s Learning Cycle (Fig. 1.1). The structure of each cycle started with a “Concrete Experience,” which was either theoretical knowledge, experiment outputs from the last step of the previous workshop cycle, or feedback, both from teachers and peers. The next step following the “Concrete Experience” in Kolb’s Learning Cycle is “Reflective observation.” In that step of the workshop, the students were encouraged to either reflect on the theoretical knowledge they were presented with, the output of their experiments, or the feedback from teachers and peers. The “Active Conceptualization” step followed, where the students made changes to their designs or prepared experiments to test design choices they had already implemented in their projects. The fourth and last step of each cycle in Kolb’s Experiential Learning Theory is “Active Experimentation.” In this final step of each cycle, the students performed environmental and energy performance analysis of their designs with either analog or digital simulation tools. The three cycles were designed to build in complexity upon each other, following Schenck and Cruickshank’s Co-constructed Developmental Teaching Theory, encouraging the students to look at the same problems from different perspectives and through the lens of each tool they used. Even though the cycles seem to have a one-directional structure, the students were encouraged to enter and reenter the cycles freely, at any step, repeating experiments alternating between different simulation tools, redesigning their projects, returning to the theoretical knowledge, seeking more information, or asking for further guidance and feedback. The goal was to introduce the students to a holistic approach to design and deepen their understanding of the subtleties of simulation output and how the different tools might affect those outputs.

The experimental workshop procedure that the students followed can be seen in (Fig. 2.1). This graph represents the whole structure of the course. It includes the theoretical part of the course, the preliminary design stage, the workshop, and the final project development stage. With this graph, we aim to show how the workshop was organically incorporated into the course curriculum, providing the students with the opportunity to experiment and reflect on their findings while simultaneously aligning the teaching and learning activities to serve the semester project development and the planned course learning outcomes while leaving space for experimentation and risk-taking.

The double-loop Action Research design (Fig. 2.2) allowed us to have a structured systematic investigation. All teaching and learning activities and the data collection and interpretation methods followed the same structure of a Learning Cycle. This allowed us to systematically improve our protocols and research design. We began the inquiry with our hypothesis that served as the first “Concrete Experience,” beginning the first research learning cycle. The Concrete Experiences in the next cycles were based on the data collected or the results of the experimentation phase. We indicated the series of patterns mentioned earlier in this paper that might lead to Design Fixations and named them “Read Threads,” which, together with the data coding protocols, served as the step of “Reflective Observation.” We made sure to incorporate those “Red Threads” in the research protocols at every level. The fourth step of each of our research cycles was the Action Research Protocols for designing and improving the teaching and learning activities that were later tested in the “Active Experimentation” phase with the students.

4.4 Participants

Twenty students participated in the workshop. They were from ten different countries, where only 35% were Norwegians. Since the course is interdisciplinary, the participants had different educational backgrounds, where the majority, about 70%, had an architectural background 20% had an engineering background, and 10% had a mixed background between architecture and engineering. 80% of the students were women, and 20% were men. About 60% of the students had no prior knowledge of the digital tools introduced in the course, and 40% had some knowledge. Only one person had in-depth prior knowledge in regard to the theory of bioclimatic design, 55% had basic knowledge, and 40% found the information and knowledge presented in the course to be new to them. When splitting the students into design teams, we made sure that there was at least one person with an engineering background in each group in order to distribute the participants more fairly.

4.5 Data collection

A large amount of data was collected and recorded during the experimental workshop. However, the aim of this paper is to discuss the outcomes of incorporating digital tools into hands-on activities and experiments and how this has affected the learning experience of the participating students. Because of this reason some of the data collected is not included in the data analysis and interpretation for this paper. The study used a mixed-methods approach, and both qualitative and quantitative data were collected and interpreted. The data collection protocols included mapping sheets for the students' backgrounds, a Learning Style Inventory Test, mapping the students' individual

styles in accordance with the “Experiential Learning” theory (Kolb 2021), Likert scale charts allowing the students to rate each activity, field notes from conversations with the students and from each presentation concluding a workshop cycle, sheets for open feedback from the students in regard to the activities, and project reports concluding the workshop. Ethical approval for collecting this data was not required since no names, ages, or other distinguishable information was collected.

The data collection procedures followed protocols that were established to put constraints on the type of data that needed to be collected and to put that data in context, which later allowed us to easily find and select data interpretation methods aligned with the methodology of this study. We named the constraints in the data collection protocols “Red Threads” and used them as a “Start List” (Saldaña 2013, 144) for the first cycle of data coding by using a Provisional Coding method. The ‘red threads’ led to four main initial categories for the Provisional Coding, those being “Background information” - for statistical purposes; “Learning outcomes” - whether the workshop activities influenced the design development and enabled the students to improve their designs on the basis of evidence in a systematic manner; “Students’ satisfaction” with the different teaching and learning activities (helpful-not helpful, neutral, and no response); and “Engagement with” and “resistance to” the different tools. Those categories revolved around whether the students used the tools and how and whether they followed the instructions or not.

4.6 Data interpretation

The data collected was manually coded in three consecutive cycles using different coding methods aligned with the research framework. Initially, the data was “themed” (Saldaña 2013, 144) and reflected upon through analytical memos in order to be systematized in a table (Table 1). This table later served to evaluate the workshop’s teaching and learning activities, what impact they had on the students’ design process, their usefulness, and the student’s engagement with the tools in the activities. A separate table was used for each cycle of the workshop in order to be able to compare and contrast the outcomes of the use of the different tools. Furthermore, the tables were aligned with the learning cycle steps of the workshop design for further coherence.

Table 1: Workshop cycles’ evaluation table template. Source: (Assembled by the authors 2023)

0. Groups	G1	G2	G3	G4	G5
1. Experiment:					
- Unplanned free experimentation (in order to discover unexpected things)					
- Planned experiments (testing of conditions)					
- Planned experiment (testing existing design)					
- Planned experiment (testing of solutions)					
2. Discovery:					
- Something surprising/unexpected					
- Something opposite to expected					
- Got confirmation on speculation/theory					
- “Saw the bigger picture”					
- Other					
- Didn’t discover anything					
3. Reflections					
- Critical reflection on own design					
- Reflections on discoveries					
- Reflections on possible solutions					
- Reflections on initial objectives					
4. Design choices					
- Due to a discovery					
- Due to an experiment					
- Due to a reflection (compromise)					
- Confirmation of initial design choices					
5. Followed instructions thoroughly					
6. Module influenced the design development					

For the first coding cycle, we used the Provisional coding method (Saldaña 2013, 144). As mentioned in the previous point, we had a “Start List” with “Red Threads” we wanted to trace throughout the workshop. Some of the provisional categories remained until the end of the coding process, and other categories emerged from the empirical data when the first cycle of coding was repeated using the Initial coding approach. In this second stage of the first cycle of coding, In Vivo and Process coding methods were incorporated to ground the findings in the data retrieved. We concluded the data coding with a second cycle incorporating a Pattern coding method, which allowed us to split, splice, and link the data (ibid.) into the final categories we used for the evaluation tables (Table 1).
By using these categories in the evaluation tables, we managed to analyze to what degree each group of students was engaged in the teaching and learning activities, to what degree they were immersed in the learning cycles, and if they managed to enter and reenter the learning cycles at different points.

5.0 RESULTS

The results of the evaluation of the teaching and learning activities and their impact on the design process of the students were collected and visually represented on the workshop framework scheme presented in (Fig. 2.1). This visual representation of the results can be seen in (Fig. 3), where the framework schemes are filled out and placed on top of the matrices mapping the students individual learning styles for each person in each group.

In the first cycle of the workshop, 75% of the students found the tool and the activities to be very useful, 10% found them informative, and 15% did not express any opinion. All five groups conducted experiments, both planned and improvised, with the heliodon, “made a discovery,” engaged in thorough reflections, and claimed that the use of the tool impacted their design choices.

In the second cycle of the workshop, even though all five groups completed the exercise following the Sol-Air approach, one group was discarded from the statistics because they opted for an alternative software for design optimization. However, all four remaining groups conducted experiments in the assigned software after the exercise, and all of them claimed to have “made discoveries” or have “seen the bigger picture.” All four groups also claimed that the second cycle and the exercise with the digital tool facilitated reflection on their design. However, only two groups claimed that the activities in this module influenced their design choices. 60% of students found this module useful or very useful, 5% found the activities informative, and 5% rated them as not useful. The remaining 20% did not express any opinion.

Due to the approaching final semester presentations and other time constraints, only two groups made use of the last tool and completed the teaching and learning activities implemented in this cycle. Only one group claimed that the activity influenced their design choices. However, 50% of the students still found that learning how to use the tool was useful and beneficial for future projects, 25% found the third cycle informative, 10% found it not useful, and 15% did not express any opinion.

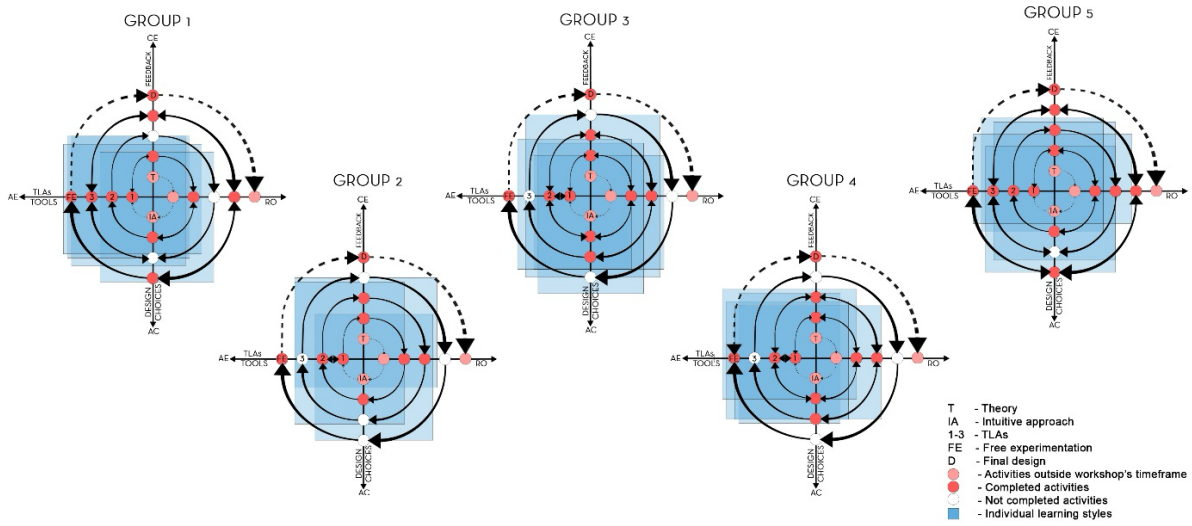


Figure 3: Visual representation of the results of the experimental workshop placed on top of the results of the learning style inventory test for each student in each group. Source: (Assembled by the authors 2023)

6.0 DISCUSSION

The processes of designing and executing the workshop led us to the development of a methodology for structured systematic investigation. Structuring the research design and research protocols following Kolb’s Learning Cycles and Schenck and Cruickshank’s Co-constructed Developmental Teaching Theory laid the basis for further investigations that will allow us to compare and contrast the results of the workshops between different years and potentially across different institutions if the opportunity arises.

6.1 Limitations and Further Work

The data analysis conducted after the workshop accentuated a few reflection points that require heightened attention for the further development of this study. In order to refine the methodology and strengthen the protocols for drawing conclusions, certain changes need to be made in the next workshop design.

For example, certain attitudes toward the workshop activities formed because of the climatic context in which the students worked. Considering that the main topic of the workshop was “Sun and Form,” and the aim was to explore solar responsive design strategies, groups that developed their concept with other bioclimatic strategies, like the relationship between wind and form, for example, perceived the workshop as not very useful. They either did not fully engage with the learning cycles, did not fully utilize the activities, or underestimated the workshop’s potential contribution to their project development.

Another point for reflection is that for some students, the fact that the activities were not graded played a role in how engaged they were in the workshop, although the target was still the improvement and development of their semester project.

The sample of only five groups is too small for any definitive conclusions to be drawn. However, the detected patterns will serve as the basis for the future development of the experimental workshop design. A second workshop is planned for the autumn semester of 2024, which will repeat the study with revised protocols based on our current results and findings. It will expand the sample size and will span over another module, combining CFD tools with a water-based streamline visualization tool focusing on the relationship between wind and form.

CONCLUSION

This article summarizes the first attempt at implementing an experimental workshop in the Climate and Built Form course, aiming to build a comprehensive methodology for conducting systematic investigations of bioclimatic design strategies through the utilization of analog and digital tools. Many reflection points can be drawn from the results. However, it is hard to establish any definitive conclusions based on those points at this stage of the study.

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Āina-based Design Solution for Indigenous Communities in Hawaii: a Pedagogy Approach

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ABSTRACT: The objective of this endeavor is to develop, evaluate, and substantiate an integrative design methodology grounded in Āina, which is tailored to address the needs of indigenous populations in Hawai'i. This methodology is operationalized through a triad of courses at Chaminade University of Honolulu. These courses are designed to facilitate a collaborative learning environment that unites students, community stakeholders, and academics through hands-on design studios, mandatory thematic courses, and optional seminars. The practical application of this design approach is examined through two key initiatives: the refurbishment of the Maunalua Fishpond Heritage Center and the conception of a modular shelter aimed at assisting the homeless and providing aid during disasters. The collaborative efforts are supported by a partnership between the Chaminade team, the Maunalua Fishpond Heritage Foundation, and the Institute of Human Services in Hawaii, with a focus on discerning and fulfilling the community's specific requirements.

KEYWORDS: Āina-based Design, indigenous knowledge, native Hawaii, design process, aina-based

INTRODUCTION

The Hawaiian worldview embodies a unique philosophy of unity and harmony, especially in the context of land and culture. This perspective, deeply rooted in tradition, emphasizes a stewardship ethic—kuleana—towards the aina (land). There is a recognized cyclical relationship of give-and-take with the environment that is reflected in architectural practices; they not only utilize but also replenish the natural resources of the islands respectfully. The bond with the land transcends mere occupation; it forms an integral part of Hawaiian identity, a lineage and narrative that encompasses both collective joy and historical trauma. This profound connection acts as a unifying force for Hawaiians, including those in the diaspora, through shared cultural roots and experiences. Academic works by Kanaʻiaupuni and Malone provide a nuanced examination of Hawaiian identity, exploring its complexities through both historical and contemporary lenses (Kanaʻiaupuni & Liebler 2005, 693; Kanaʻiaupuni & Malone 2006).

However, climate change poses a significant threat to this intrinsic relationship with the environment. Hawaii faces escalating environmental challenges, such as rising sea levels, intensified hurricanes, and water contamination, which threaten coastal integrity, infrastructure, and freshwater sources (Finucane et al. 2013). The physical impacts are intensified by economic constraints, with spiraling insurance premiums and construction costs. The state's unique and fragile ecosystems are also at risk due to deforestation, land development, and invasive species (Spencer et al. 2020). For Native Hawaiians, the repercussions are profound, threatening traditional fisheries, agricultural lands, and leading to the displacement of communities. These developments sever cultural ties and create economic and health adversities.

The convergence of resource scarcity, climatic shifts, and environmental degradation burdens indigenous communities. These communities, which already encounter numerous adversities, are striving to preserve, restore, and rebuild their heritage and properties in culturally meaningful ways (Hu et al. 2023). The situation is a clarion call for urgent climate action and support for Indigenous communities that are disproportionately affected by these changes.

1.0 DESIGN NEEDS

Despite Hawaii's distinctive culture and environmental and social challenges, architectural and interior design education, influenced by Western pedagogical models, emphasizes theoretical knowledge over practical, real-world experience (Sanoff 2003; Seidel 1995). This approach often neglects the deep historical and social contexts crucial to architecture (Salama 2008). Traditional design education starts with a pre-design phase, where site visits, client interviews, and research lay the foundation for understanding the project. However, this research tends to be superficial, lacking the depth and thorough investigation needed for meaningful insight. A significant gap in this education is its focus on the physical aspects of the present rather than the narratives and knowledge of people, history, land, and community. Consequently, students may become disoriented, missing the chance to engage with the project's context critically. The tendency is for lectures to provide ready-made interpretations, which can limit students' critical thinking and comprehensive information processing (Salama 2008). Current teaching methods tend to promote only a superficial engagement with information rather than encouraging a deep connection with the project's essence, which should integrate the land's stories and the community's heritage (Fisher 2004; Groat 2000).

Hawai'i offers a wealth of knowledge and indigenous practices from which designers can learn. Moving away from Western-centric approaches in design education, there's a significant benefit in embracing Āina-based learning,

which incorporates the land's authentic information into design challenges. For indigenous communities, the respect for the land and people is crucial, and design education should provide students with experiences that place the land within its historical and cultural context.

Understanding Āina means recognizing the land's past, present, and future, and Āina-based pedagogy encourages students to explore these dimensions through the Hawaiian concept of Welina—a practice of inclusion and welcoming (Chun 2006). This approach emphasizes the importance of integrating local community partners and cultural experts into the educational process, allowing students to access indigenous knowledge and connect with the land's history and stories. Community members become co-creators in the design process, bringing invaluable insight from their lived experience and knowledge of the land's resources. Such integration fosters interactive and dynamic learning, enriching the design process and enabling students and instructors to collaborate on more meaningful design solutions that are informed by a deep connection to the land and its people.

2.0 ĀINA-BASED DESIGN APPROACH

2.1. Definition

In Hawai'i, the principle of Aloha ʻĀina (appreciation of the land) symbolizes the profound connection between land, nature, and people, forming a foundational element of Native Hawaiian strength. To the indigenous ancestors, or kupuna (ancestor), the land, imbued with the spiritual essence or mana, was synonymous with life itself. For Kānaka Maoli(Native Hawaii), the land is cherished not only for sustaining life but also as the resting place of their ancestors, making it an extension of family and a source of gratitude.The relationship with the land transcends mere ownership; it is a reciprocal bond where the land nurtures as it is nurtured, respected, and cared for. This is embodied in the concept of Mālama (To take care) ʻĀina—stewardship of the land—which reflects the kuleana (responsibility), or responsibility, of Native Hawaiians to sustain and manage the land's resources with care.

Āina-based design diverges from conventional, sustainable, and environmentally friendly methods primarily in two ways. It harnesses traditional knowledge for material use, spatial planning, symbolic representation, and climate adaptability. The design process also follows building typologies that are rooted in timeless concepts rather than contemporary market trends. As Robert Jan Van Pelt and William Westfall outlined, a building is considered a timeless type that symbolizes its purpose—the essence of what the structure represents and serves within its community. This typology is evident across different kinds of structures, where the design and layout reflect their intended function, as with a temple designed for communal gatherings and celebrations, embodying the spiritual and social activities that take place within *(van Pelt & Westfall 1991)*.

2.2. Design principles

As illustrated in Figure 1. An *Āina*-based design approach comprises three pillars: community (Native Hawaii) participation, student-participation and research-engagement. Community participatory design is crucial for creating inclusive, effective, and sustainable solutions that address real-world challenges and have a positive impact on the lives of the people they serve. It fosters collaboration, understanding, and shared ownership, ultimately leading to better outcomes for everyone involved. Research-driven teaching, or evidence-based teaching, is crucial for improving student learning outcomes, promoting engagement and motivation, tailoring instruction to individual needs, and fostering continuous improvement in the education system (Figure 1). Using evidence-based practices, educators can create more effective, inclusive, and equitable learning environments that benefit all students. An *Āina*-based design approach has three fundamental principles: bioclimatic design, cultural symbolism and design within means(materials, resources). The study explores the design parameters of natural ventilation, material, space layout, natural view, and lighting**.**

Student participation is through service-learning, a teaching and learning strategy that integrates community service with academic instruction. It involves engaging students in meaningful community service activities directly related to the course content they are learning and addressing identified community needs. Through service-learning, students can apply their classroom learning to real-world situations and develop skills and knowledge that are valuable both academically and personally. Service-learning also fosters a sense of civic responsibility and encourages students to become active and engaged members of their communities.

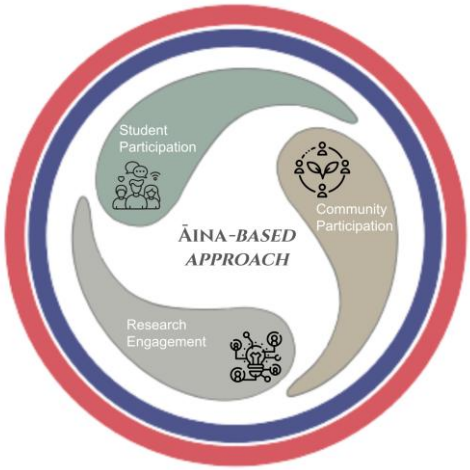


Figure 1: Three pillars of Aina-based approach. Source: (Author 2023)

2.3. Learning from vernacular architecture

The genesis of Hawaiian vernacular architecture can be traced back to a synthesis of the Hawaiian islands' natural bounty and traditional building methods originally introduced by the earliest known settlers from the Marquesas Islands (Randall 1987).These settlers adapted the designs of their Polynesian kin into their construction, leading to the prevalence of rectangular floor plans in the architecture across Polynesia, which includes regions like Hawai'i, Fiji, Tahiti, New Zealand, and New Guinea.

In the Hawaiian tradition, various hale, or structures, were constructed, each with a distinct function. As illustrated in Figure 2, the hale heiau was a sacred space for worshiping Hawaiian deities like Lono, Ku, and Madame Pele. The hale *Mua* served as a men-only sleeping quarters, with strict kapu (taboo) laws enforced under penalty of death. The hale *Noa*, in contrast, was a communal family sleeping area. Women had their designated eating area in the hale *Aina*, while men were excluded. Food preparation took place in the hale *Kahumu*. Women's crafts, such as mat weaving, were performed in the hale *Kua*, and the hale *Wa'a* was used for storing canoes. Despite their varied uses, all hale shared a commonality in their foundational design, utilizing the same underlying structure, tools, and materials, a testament to the ingenuity and resourcefulness of traditional Hawaiian architecture.

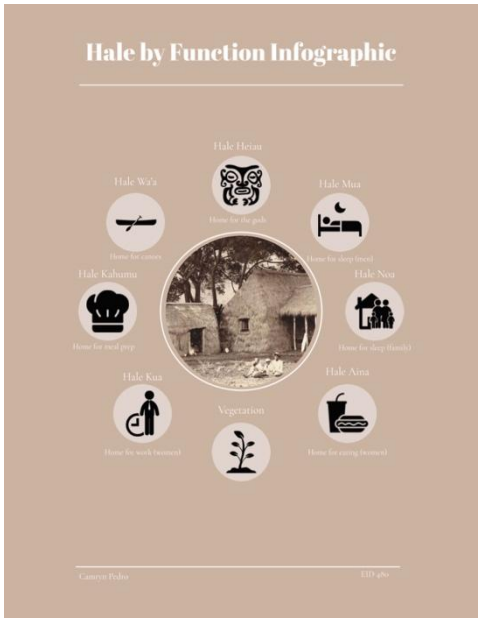


Figure 2: Hale by function infographic. Source: (Camryn Pedro 2023)

Each Hale, a traditional Hawaiian structure, was crafted from materials gathered from the local environment. The construction primarily utilized three materials: wood for the framework, rope for binding, and leaves for thatching. The structural framework, including posts and rafters, was fashioned from the unprocessed trunks and branches of hardwood trees. Premier hale construction often employed hardwoods like Naio, Uhiuhi, Kauila, Mamane, and Koa, with koa being preferred for canoe making. Lesser quality structures sometimes used ohia lehua, while hale dedicated to deities were made with lama wood.

Today, if one were to construct a hale, suitable hardwoods such as ironwood, Kiawe, eucalyptus, strawberry guava, ohia, and mangrove would be chosen, as these are readily available in the Hawaiian Islands. The roofs and walls traditionally consisted of grass or leaves, typically pili or coconut leaves. In contemporary construction, materials

like Pili, Kualohia, Pueo, Kawelu, sugarcane leaves, and ti leaves would be appropriate choices, aligning with traditional practices.

3.0 OVERALL COURSE DESIGN

The educational goals are woven into a pair of courses overseen by two instructors: EID 271, which focuses on Materiality in Interior Design Studio, EID 471 for Senior Studio with a commercial slant, and EID 480 dedicated to Independent Study. Here, students delve into spatial designs that empower individuals to shape their surroundings. These personal spaces are crafted to foster a sense of place based on reciprocal respect and sustainability (Godbolt & Hoho 2006). Additionally, the curriculum encourages the thoughtful selection of materials and the incorporation of natural elements, cultivating a sense of belonging and comfort. These principles align with the values upheld by Marianist teachings and Native Hawaiian traditions.

3.1. EID 271: Materiality in interior design

The studio project embraces an Āina-based design methodology, which is informed by the three pillars depicted in Figure 2. It centers on an Āina-inspired design for an emergency/homeless shelter, a choice motivated by the acute housing crisis affecting many native Hawaiian communities. These communities face a disproportionate lack of housing options, a situation exacerbated for low-income indigenous groups and predicted to worsen with climate change impacts (Callies 2010). In response to a request from the Institute of Human Services (IHS), a non-profit organization, the second-year design studio course EID 271: Materiality in Interior Design took on this project for a semester. The task set for students was to consider the living quality of people under severe stress and to conceptualize design solutions that would align with the needs of these communities and the values of Marianist education. The project aimed to delve into the essence of Āina-based design within the context of Hawai'i, examining ways to uphold human dignity and safety amidst the crisis faced by the shelter's temporary inhabitants.

In this course, students scrutinize how design concepts are manifested through materiality, with a keen focus on weaving suitable materials, finishes, and products into the fabric of interior spaces. The studio scrutinizes 'materiality' as a pivotal factor in the development of interior spaces, assessing how the integration of materials influences spatial quality. From the outset, community members and Hawaiian cultural experts were engaged to provide valuable feedback throughout the design process, from the initial concepts to the design development phase. During the pre-design phase, in-depth discussions on Hawaiian vernacular design and the application of indigenous knowledge in selecting interior building and finishing materials were facilitated with literature and insights from in-house cultural specialists and the director of the Maunalua Fishpond Heritage Center (MFHC). Students were then tasked to interpret and integrate the insights gleaned from these discussions, as well as the readings, to underscore the significance of the historical, social, and cultural contexts relevant to the design challenges presented within the project, as illustrated in Figure 3 and 4.





Figure 3 and 4: Student work: concept development based on cultural reflection; integration of indigenous pattern work with functional use . Source: (Tina-Marie Dust 2023) and (Jazlynne Williamson 2023)

3.2. EID 471: Senior design studio

Grounded in the Āina-based design philosophy, this capstone studio course is dedicated to the redesign of the Maunalua Fishpond Heritage Center (MFHC), which is the steward of the Kānewai Spring site, ensuring its management, preservation, and protection for the benefit of Hawai'i's community and residents. The course represents an advanced integration of academic learning with professional application. It challenges students to apply their cumulative knowledge from the interior design curriculum, requiring them to employ comprehensive problem-solving skills, technical expertise, theoretical insight, and research acumen throughout the semester-long project.

The studio operates under the Āina-based design framework, anchored by three key principles as depicted in Figure 2. The project partners with MFHC, a non-profit organization co-founded by Chris Cramer and Jeannie Johnson in 2007 to safeguard the heritage of Hawaiian fishponds, detailed in Figure 4. The organization was instrumental in the enactment of Act 210 in 2010, securing protection for Hawaiian fishponds across the state. The Kānewai Spring, integral to this project, is one of Honolulu's last significant natural springs, delivering around 840,000 gallons of fresh water daily to the coastal ecosystems, from Kānewai Fishpond to Paiko Lagoon Wildlife Sanctuary and ultimately into Maunalua Bay.

The course design incorporates service-learning modules, threading leadership and community engagement opportunities throughout the semester. Students are expected to lead these initiatives, fostering community ties and dialogue. Their work with the Maunalua Fishpond Heritage Center will demonstrate their grasp of the Āina-based design approach, an educational journey illustrated in Figure 5.



Figure 5: Student work: balance between outdoor and indoor environment; integration of traditional construction methods and materials. Source: (Camryn Pedro 2023)

CONCLUSION

The Āina-based design approach is the genesis of a design process that is sustainable and inclusive, prioritizing the historical, social, and cultural significance of the land rather than just the geographic location. This method transcends the realm of design education, extending into professional practice and various fields, driven by the pillars of community engagement, leadership through student participation, and a commitment to research. This philosophy cultivates a collaborative environment where ownership of projects is collective and learning is an interactive experience. Through this process, students immerse themselves in research, engage in substantive dialogues with community members, and reflect critically on the insights gained, integrating them into their broader comprehension.

Although this concept originated in Hawai'i, with its deep reverence for the land—Āina—it advocates for an educational focus that fosters a more effective, inclusive, and equitable learning environment beneficial to all students. Contrasting with Western educational models that often position humans at the center of the built environment, this approach advocates for a design ethos where the significance of the land's history and ecosystem is paramount.

As the world faces increasingly drastic climate changes, the land serves as a poignant reminder of our transient stewardship over it. We are reminded that we do not, and never will, own the land. This awareness must be re-integrated into educational systems, empowering students, educators, and community members to co-create futures that are socially responsible, historically aware, environmentally sound, and culturally rich, ensuring sustainability for generations to come.

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Interdisciplinary Collaboration and Inclusivity: Methodological Innovations in Architectural Practice and Pedagogy

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ABSTRACT: This paper explores interdisciplinary and inclusive methodologies in architectural education, addressing contemporary socio-technical challenges. It highlights the role of collaborative frameworks in fostering dynamic learning environments and innovative pedagogical strategies. By integrating Industry 5.0 methodologies and digital mapping, we examine their impact on design processes, material innovation, and urban discourse. Through co-production and computational design techniques, we showcase the benefits of interdisciplinary collaboration in shaping future architects. Additionally, we discuss how these approaches enhance problem-solving, teamwork, and critical thinking skills essential for contemporary architectural practice.

This study also investigates how emerging technologies in Industry 5.0 facilitate human-centered design, sustainability, and resilience in built environments. By leveraging digital tools, automation, and adaptive systems, architectural education can better prepare students for evolving industry demands. The paper presents practical case studies from our design studios, demonstrating the transformative potential of these methodologies. This study offers valuable insights for educators seeking to enhance inclusivity, adaptability, and innovation in architectural pedagogy.

KEYWORDS: Interdisciplinary Collaboration, Inclusive Architectural Practice, Industry 5.0; Transformative Pedagogy, Inclusivity

INTRODUCTION

The evolving landscape of architectural design and pedagogy is increasingly shaped by interdisciplinary collaboration and inclusivity. This paper critically examines the transformative impact of these methodologies within our design studios. We highlight the role of Industry 5.0 technologies in fostering innovation, adaptability, and sustainability in architectural education. By leveraging automation, data-driven decision-making, and human-centric design approaches, we explore how architectural pedagogy can effectively address contemporary socio-technical challenges. In an era marked by rapid technological advancements, globalization, and the urgent need for sustainable design, architecture faces complex challenges that extend beyond conventional design processes. These challenges involve environmental, social, and technological dimensions that require a multidisciplinary response. Our research emphasizes two fundamental pillars: interdisciplinary collaboration and inclusivity. By integrating diverse disciplines and embracing varied perspectives, we create a pedagogical framework that nurtures creative problem-solving and adaptability.

Industry 5.0 methodologies enhance architectural education by promoting human-machine collaboration, automation, and sustainable material innovation. Through data-driven design, computational fabrication, and smart resource management, students develop critical skills necessary for future industry demands. These methodologies provide new ways to engage with urban planning, structural efficiency, and ecological resilience, fostering an educational paradigm that moves beyond traditional disciplinary boundaries. As we delve into these intersections, we analyze how Industry 5.0 technologies influence spatial design, social engagement, and material innovation. The integration of these methodologies in architectural pedagogy enables students to develop holistic and sustainable solutions for contemporary urban challenges. Our study presents case-based insights from our design studios, demonstrating the tangible benefits of interdisciplinary collaboration and Industry 5.0-driven innovation.

1.0 EMERGING TECHNOLOGIES IN ARCHITECTURAL EDUCATION AND INTERDISCIPLINARY APPROACHES

It would be impossible to overstate the importance of technology in today's world. The introduction of various technologies, regardless of their scale, has had a profound impact on our daily lives and the way we coexist as a community (Mehan et al., 2023; Jacobs et al., 2021). A result of technological advancements, people are intuitively entering the world of homogenization; this phenomenon is known as globalization. Digital technology has reshaped social communication and expression practices, creating spaces for information organization, data preservation, and the creation and distribution of knowledge and cultural values (Jehel *et al.* 2023). Virtual reality and architecture

can both look back on a long history together (Lin and Hsu 2017). Digitalization can help improve education in architecture and urban planning by opening new doors, making things run more smoothly, encouraging teamwork, and adding new ways of designing (Boodaghi et al. 2022). Digitizing architecture saves time and money and makes it possible to investigate new study questions (Radović *et al.* 2020). However, the way architecture classes are set up now might not prepare students well enough for the digital age. This shows that the lessons need to be looked at again and digital design methods need to be added (Wu and Zhou 2009).

Tech advances and new ideas, like computing and machine learning, can make the architectural education sector more valuable and the creation process more efficient (Fonsati 2022).Digital design tools have more potential and facilities than old-fashioned ones because they let people from architecture and related fields work together and try out new ways to use architecture (Gheorghe 2019).There is foot print of digital technology in green building design makes the process more efficient and let you look at how space is organised in urban design (Abdullah and Hassanpour 2021). Industry 5.0 technologies play a critical role in influencing spatial design, social engagement, and material innovation. The integration of these methodologies in architectural pedagogy enables students to develop holistic and sustainable solutions for contemporary urban challenges. Our study presents case-based insights from our design studios, demonstrating the tangible benefits of interdisciplinary collaboration and Industry 5.0-driven innovation. Industry 5.0 emphasizes human-machine collaboration, automation, and adaptive design processes to create efficient and responsive architectural solutions. By leveraging intelligent digital systems, robotics, and advanced material science, these technologies enhance design accuracy, efficiency, and sustainability. The transition towards Industry 5.0 fosters a shift from traditional architectural workflows to more interactive, data-driven, and environmentally responsible methodologies.

Both Industry 5.0 and architecture have a long-standing relationship, with the integration of advanced automation, smart materials, and data-driven design becoming standard practice in architectural processes. These technologies create responsive and adaptable design solutions that improve efficiency, sustainability, and collaboration (Mostafavi et al. 2024; Tappert et al. 2024; Suryawinata 2021). Industry 5.0 focuses on human-centric innovation, bridging intelligent systems with architectural workflows to enhance productivity and resilience (Mostafavi and Mehan 2023). Moreover, industry 5.0 technologies have a direct impact on the design and learning process of architecture and urban studies (Al-Suwaidi et al. 2023; Mehan and Mostafavi 2023a). As a result, architectural education is embracing new methodologies, tools, and automated techniques to refine the design process. The integration of robotics, computational automation, and smart manufacturing enables architects to engage with emerging systems that optimize sustainability, precision, and material efficiency (Bardi 2019). These advancements transform architectural pedagogy by preparing students for evolving industry trends and fostering problem-solving skills that align with contemporary technological innovations (Lu 2022). Furthermore, the integration of architectural navigation has been explored in numerous experiments using digital technologies in urban planning and building design (Roupé *et al.*, 2014; Castronovo *et al.* 2013). According to Nee and Ong (2013), display technology has advanced significantly over time, extending beyond traditional computer screens into practical applications. Compared to earlier iterations, modern visualization tools have undergone substantial refinement. These advancements are largely attributed to increases in computing power and innovations in motion tracking technology (Lin and Hsu, 2017). Enhanced display resolutions and precision tracking systems have expanded the capabilities of digital tools, unlocking new opportunities for architectural design education. As a result, students can engage with highly interactive and dynamic learning environments that support spatial visualization, real-time data integration, and advanced modeling techniques (Lin and Hsu 2017).

According to the Lin and Hus (2017) at present, students within the classroom engage in the process of proposing ideas and engaging in discussions using sketches and models to envision the anticipated outcomes of their projects and during the initial phase of architectural design, the development of ideas relies heavily on the utilisation of quick sketching. As the conceptualization progresses, it becomes necessary to transition from an abstract idea to the creation of physical prototypes in the form of architectural structures or spatial designs (Mehan 2023a). During this phase, it has been suggested by several studies that learning within an interactive environment has the potential to enhance spatial cognition in individuals who are new to a particular subject (Abdelhameed 2013; Angulo 2013). Numerous scholarly investigations have been conducted on the topic of acquiring architectural design skills using the utilization of emerging technologies (Abdelhameed 2013; Brown and Green 2016). The development of interactive techniques can be categorised into multiple stages based on technology limitations (Creagh 2003). Initially, the concept of creating an immersive environment inside the physical world involved the utilization of cumbersome apparatus and the display of visual content on a screen. With the advancement of projection and 3D image techniques, the Cave Automatic Virtual Environment (CAVE) has emerged as a viable option for providing viewers with a fully immersive experience. This is made possible with the integration of motion capture technology, allowing users to interact inside a virtual environment that surrounds them on all sides (Majid and Fuada 2020).The new lightweight virtual reality gadget exhibits considerable potential for architectural design instruction due to its mobility, well-prepared platform, and compatibility with other computer-aided design and drafting Computer Aided Architectural Design (CADD) tools (AL-SUWAIDI *et al.* 2023). Emerging technologies in architectural education can prove situation for e-learning. Moreover, according to (Majid and Fuada 2020; Goyal *et al.* 2021; Bhuasiri *et al.* 2012), there are many issues in e-learning such as advantages, disadvantages, challenges (Mehan 2023b). These issues have been grouped according to the stakeholders of e-learning, where the stakeholder is anyone who is a constituent of an organization, learners, instructors, course designers, employers, educational institutes, accreditation bodies. Advantages of e-learning include flexibility and convenience for learners to access learning materials anytime and anywhere across the globe (Mehan 2023d; 2023e). Cost-effectiveness for educational institutes and learners as it eliminates the need for physical classrooms and travel expenses. Personalized learning experiences for learners with different learning styles and preferences. Increased access to education for learners

in remote areas of society. Disadvantages of e-learning include Lack of face-to-face interaction between learners and instructors especially in field of design that is essential, which can lead to a lack of motivation and engagement. Limited social interaction and networking opportunities for learners. These advantages and disadvantages can impact the various stakeholders involved in the education industry differently. For example, learners may benefit from the flexibility and convenience of e-learning, while instructors may struggle with the lack of face-to-face interaction and difficulty in assessing the quality of online learning materials. Educational institutes may benefit from the cost-effectiveness of e-learning, while accreditation bodies may need to ensure that the quality of education is not compromised in the online learning environment.

Industry 5.0 methodologies can be applied throughout every stage of a building's life cycle, offering data-driven insights that optimize performance and sustainability (Mehan and Mostafavi 2024; Majid and Fuada 2020). Therefore, with capturing these data from give us opportunity to address the existing unexpected problems to prevent future problems in learning and designing process of architecture. For example, data visualisation and predictions are the most important parts of the smart city idea. Researchers can use virtual reality to look at different "what-if" situations in real time (Jamei *et al.* 2017). When it comes to design education, emerging technologies is one of the most useful and potentially useful immersive learning technology (ILTs) and for new designers, the process of design takes skill and creativity, and their personal architectural experiences have a substantial impact on it (Ummihusna and Zairul 2022).

2.0 INCLUSIVITY AND INTERDISCIPLINARY APPROACHES IN ARCHITECTURAL PEDAGOGY

The value of interdisciplinary education in architecture is also reflected in the integration of technological advancements and architectural practices (Mehan and Mostafavi 2023b; 2023c). The convergence of digital technology, such as computational design and digital fabrication, with traditional architectural knowledge broadens the scope and depth of architectural education (Oxman 2017). This blend prepares students to navigate the rapidly evolving technological landscape in architecture, equipping them with the skills to innovate and adapt. For instance, the use of digital modeling and simulation tools in environmental design courses enables students to experiment with sustainable building practices and energy-efficient design solutions (Kolarevic and Klinger 2008).

The integration of inclusivity and co-production methodologies in architectural education, highlighted using emerging technologies, provides a transformative platform for more inclusive and participatory design processes (Mehan 2020; 2015). Emerging technologies has been utilized extensively across various educational stages, proving particularly effective in disciplines requiring a deep understanding of complex spatial concepts and dangerous situations (Shelton and Hedley 2002; Wang. 2009). In the context of architecture and construction (AC), Industry 5.0 technologies foster an enhanced level of spatial understanding and engagement, which is crucial in urban planning and design education (Wang 2009; Wulandari et al. 2021). The application of industry 5.0 technologies in architectural education aligns with the industry 4.0 principles, addressing the gaps in conventional teaching methods and contributing significantly to the pedagogical and technical advancements in the field (Shelton and Hedley 2002). Additionally, the concept of universal design in architecture, which advocates for creating spaces that are accessible to all, regardless of age, ability, or other factors, is gaining traction in architectural pedagogy (Steinfeld and Maisel 2012). This inclusive approach is particularly relevant in the context of aging populations and the increasing need for accessible public spaces (Mehan 2022; Mehan and Jansen 2020). By embedding principles of universal design in architectural education, future architects are trained to consider a wide range of human experiences, leading to the creation of more inclusive and adaptable built environments (Goldsmith 2000). Furthermore, the intersection of architectural pedagogy with social and cultural diversity plays a pivotal role in shaping the architects of tomorrow (Mehan and Stuckemeyer 2023 a; 2023b).

Embracing cultural diversity within architectural education fosters a global perspective and an appreciation for the rich tapestry of architectural traditions worldwide. This approach allows students to explore architectural solutions that resonate with various cultural backgrounds and societal contexts. In doing so, it not only broadens their design vocabulary but also promotes cross-cultural understanding and sensitivity. Moreover, architectural pedagogy is increasingly recognizing the importance of gender diversity and equity within the field. Efforts are being made to create inclusive environments where women and individuals of all gender identities can thrive. This includes addressing historical gender imbalances in architecture and promoting gender-sensitive design practices. By actively promoting gender diversity and equity in architectural education, the profession becomes more reflective of society's diversity, fostering innovation and creative solutions that cater to the needs and perspectives of all individuals. These interdisciplinary and inclusive approaches not only prepare students for the challenges of the modern architectural landscape but also contribute to the creation of more sustainable, accessible, and culturally sensitive built environments.

3.0 TECHNOLOGICAL INTEGRATION IN ARCHITECTURAL DESIGN STUDIOS

The integration of Industry 5.0 methodologies into architectural education has emerged as a pivotal development that enhances the educational experience. A key aspect of this shift is the emphasis on human-machine collaboration, sustainability, and adaptive design approaches (Mostafavi et al. 2024; Tappert et al. 2024). Industry 5.0 promotes a synergy between advanced digital tools and human creativity, ensuring that technology serves as a facilitator rather than a replacement for architectural innovation (Mostafavi and Mehan 2023).
One significant advancement is the use of data-driven decision-making, automation, and intelligent design systems to enhance architectural pedagogy. Digital simulation tools and computational modeling enable students to engage with course content in a dynamic and interactive manner (Wulandari et al. 2021). These technologies foster deeper

comprehension of complex spatial relationships, material behaviors, and sustainable design strategies. As a result, students gain valuable insights into real-world architectural challenges and develop problem-solving skills rooted in data analysis and contextual responsiveness (Mostafavi et al. 2024; Jamei et al. 2017).

Furthermore, recent strides in Industry 5.0 have ushered in a new era of data visualization and analysis in architectural design. These technologies empower architects, clients, and stakeholders with the capability to interpret and integrate complex datasets into the design process (Oufir et al. 2020). The ability to analyze material performance, environmental impact, and spatial configurations in real-time enhances decision-making and promotes sustainable, human-centric architectural solutions (Suryawinata 2021).

These developments underscore the profound impact of Industry 5.0 technologies on the advancement of architectural education. They contribute not only to enriched pedagogical approaches but also to the practical domain of architectural design. As technology continues its rapid evolution, architectural education remains at the forefront of innovation (Mehan 2024). The strategic integration of these methodologies promises to cultivate a new generation of architects equipped with the knowledge and skills to navigate the multifaceted challenges of contemporary design in an increasingly digitized and sustainable built environment.

4.0 ENHANCING URBAN DESIGN THROUGH INDUSTRY 5.0 AND DIGITAL COMPUTATIONAL PRACTICES

This section explores the theoretical advancements and methodological innovations in urban design enabled by Industry 5.0 and digital computational practices. The shift towards Industry 5.0 emphasizes human-centered and sustainable technological integration, fostering a more adaptive and resilient urban environment. Unlike previous industrial paradigms, Industry 5.0 seeks to balance automation with human expertise, ensuring that technological advancements serve social, cultural, and ecological needs rather than merely increasing efficiency.

The implementation of Industry 5.0 principles in urban design enables architects and planners to leverage intelligent data-driven models, predictive analytics, and decentralized decision-making processes. These methodologies enhance spatial planning, resource optimization, and socio-environmental responsiveness. By integrating digital twins, advanced simulations, and real-time urban analytics, designers gain a deeper understanding of complex urban dynamics and emergent spatial patterns. Additionally, Industry 5.0 facilitates interdisciplinary collaboration by bridging technological advancements with participatory governance, ethical AI integration, and inclusive design strategies. This paradigm shift moves beyond the deterministic nature of past industrial revolutions, embracing co-creation, adaptive urban strategies, and context-sensitive design approaches. Furthermore, human-machine collaboration fosters a more nuanced design process where digital intelligence augments human creativity, leading to more responsive and sustainable urban solutions. In summary, this section highlights the theoretical foundations and transformative potential of Industry 5.0 in shaping urban design discourse. By emphasizing ethical technology use, human-centric innovation, and ecological sustainability, Industry 5.0 redefines the relationship between digital computation and the built environment. The future of urban design relies not only on technological advancements but also on the ability to harness them within a socially and environmentally responsible framework (See Fig.1).

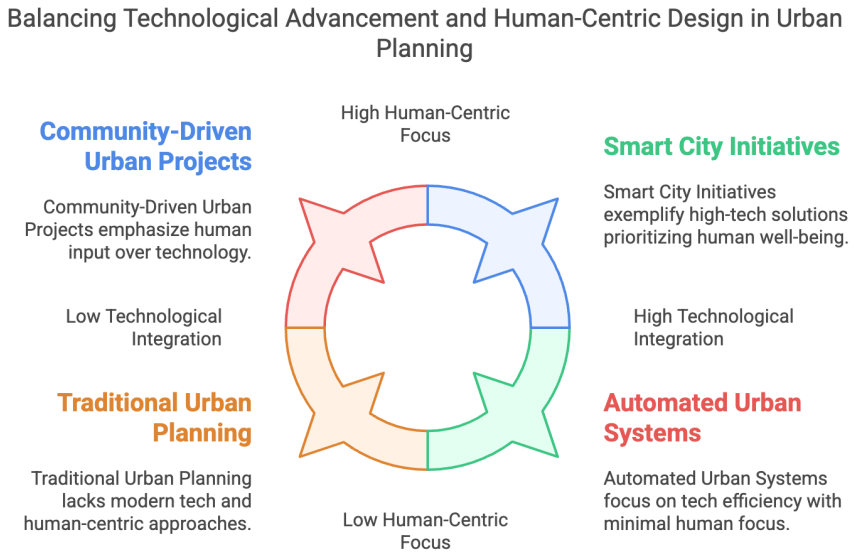


Figure 1. Framework for Balancing Technological Advancement and Human-Centric Design in Urban Planning. This diagram categorizes urban planning approaches based on their level of technological integration and human-centered focus, highlighting four key paradigms: Community-Driven Urban Projects, Smart City Initiatives, Automated Urban Systems, and Traditional Urban Planning. Source: (Authors 2024)

CONCLUSION: ADVANCING ARCHITECTURAL EDUCATION THROUGH INDUSTRY 5.0

This paper has examined the transformative role of interdisciplinary collaboration, inclusivity, and Industry 5.0 methodologies in architectural education and practice. By integrating human-machine collaboration, automation, and data-driven decision-making, Industry 5.0 fosters a new paradigm that enhances sustainability, adaptability, and innovation in the built environment. The evolution of architectural pedagogy necessitates a shift towards frameworks that integrate computational design, ethical AI, and participatory governance to address contemporary socio-technical challenges.

Our exploration of Industry 5.0 underscores its potential to reshape architectural education by promoting human-centric innovation, material sustainability, and enhanced design methodologies. Through case-based insights, we have demonstrated how these emerging technologies provide architects with the tools to engage in dynamic problem-solving, collaborative workflows, and responsive urban development. The interplay between digital intelligence and human creativity offers new opportunities for rethinking design processes in a socially and environmentally responsible manner. Furthermore, the emphasis on inclusivity within architectural pedagogy highlights the need for equitable and diverse approaches to education. By fostering interdisciplinary collaboration and ethical design practices, architectural curricula can evolve to prepare students for an industry that increasingly values sustainability, resilience, and community engagement. An essential component of this shift is the acknowledgment of the interdependencies between emerging technologies, environmental responsibility, and the social dimensions of design. These elements must be woven into architectural pedagogy to ensure that future practitioners are equipped with both technical proficiency and a deep ethical commitment to the built environment. Industry 5.0 also calls for a critical reassessment of conventional architectural workflows. The integration of intelligent automation and adaptive manufacturing techniques challenges traditional design processes, opening avenues for more responsive and context-driven approaches. This transformation necessitates new pedagogical models that emphasize experiential learning, computational literacy, and ethical decision-making. Architectural education must evolve to incorporate frameworks that foster both critical thinking and technical fluency, enabling students to navigate the complexities of contemporary urban and architectural challenges.

Moreover, Industry 5.0 encourages cross-disciplinary engagement, bridging the gap between architecture, engineering, urban planning, and environmental sciences. Such collaborations enhance the capacity for architects to design resilient, smart, and sustainable urban environments. By embracing an interdisciplinary approach, future architects will be better prepared to address global challenges such as climate change, resource depletion, and socio-spatial inequalities. The application of digital twins, real-time simulations, and predictive analytics within architectural education further enhances this potential, providing students with new tools for scenario-based planning and impact assessments.

Ultimately, Industry 5.0 presents a crucial opportunity for architecture to move beyond conventional methodologies and embrace an adaptive, forward-thinking approach. As educators and practitioners, it is imperative to continue exploring the integration of technological advancements within a human-centered framework, ensuring that architectural innovation remains aligned with social, ecological, and ethical imperatives. The continued refinement of Industry 5.0 applications in architectural pedagogy will contribute to a more inclusive, responsive, and resilient built environment, ensuring that the discipline remains at the forefront of technological and social progress.

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The Profession and the Discipline: Some Thoughts on Healthcare Design Teaching in the USA

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ABSTRACT: As healthcare design is gradually becoming a specialized area within architecture, many schools in the USA are proposing and implementing different curricular models. A comparison of these indicates non-agreement in the essential needs of these graduates. Additionally, the two professional credentialling agencies for healthcare designers also have dissimilar criteria. The questions thus are: what knowledge and skills do graduates interested in healthcare design need, what does the profession expect, and how can the academia be appropriate?

This paper collects data from public domains of each organization. It analyzes the criteria of the credentialling agencies through content analysis of their examinations and compares the curriculum of six healthcare certificates in leading US schools. Additionally, it presents the results of an online survey of eighty-six healthcare design professionals that was conducted to understand the profession's view of what skills and knowledge healthcare architects need. From these, the paper identifies common areas and maps out discrepancies. Of special interest, this paper discusses the duality between the inclusive characteristic of design and the exclusive nature of research, and how they can be understood and addressed in healthcare design teaching. It breaks down the various aspects of design and research and maps them to find actionable intersections for the benefit of educating healthcare designers.

KEYWORDS: Healthcare Design Education, Credentialing in Healthcare Architecture, Evidence-Based Design (EBD), Architectural Curriculum Development, Design–Research Integration

INTRODUCTION

Healthcare and healthcare design in the United States has changed drastically in the last two decades. Arguably, the genesis for this altered attitude is the publication of the Institute of Medicine titled "To Err is Human: Building a Safer Health System" (2000). Its stark portrayal of the immensity of hospital related errors and preventable deaths, never previously reported, resulted in a national agenda for improving all aspects of healthcare delivery. Various organizations and think tanks contributed to this agenda, identifying practice, finance, and building models that could contribute to better healthcare. For example, the Centers for Medicare and Medicaid Services (CMS) adopted a value-based program that linked Medicare payments to reduction of Hospital-Acquired Conditions (HAC) in the inpatient setting. (Centers for Medicaid and Medicare Services, Hospital-Acquired Condition Reduction Program)

A subsequent publication of the Institute of Medicine brought out the importance of the physical environment, and hence that of architects. (Institute of Medicine 2004). This report suggested that the physical design of healthcare facilities greatly influences nurse efficiency and this in turn increases patient safety. For example, poor layout of patient care units and patient rooms can decrease the time nurses have to access and provide direct care of patients. On other factors too, the role of design gradually became more and more pronounced such that calls to consider architects as public-health professionals have emerged (Fisher 2019).

Added to these is the fact that the healthcare industry has also grown tremendously in the last decade. U.S. health care spending grew 4.1 percent in 2022, reaching $4.5 trillion or $13,493 per person. As a share of the nation's Gross Domestic Product, health spending accounted for 17.3 percent (Centers for Medicare and Medicaid Services 2022). Much of this spending is on capital investments. In 2023 US spent 63.35 billion in healthcare construction, one of the highest building categories. Thus, the scope and opportunities of healthcare architects keep on increasing.

While healthcare architects have access to a large and increasing market, they are also being called on to be more responsible about their proposals. One outcome from such conditions is the increase of evidence-based design. This is the process where design decisions are made with an informed client and are based on the best available information from credible research and evaluations of projects. Critical thinking is required to draw rational inferences about design from information that seldom fits a unique situation precisely. (Hamilton 2004). This process is based on knowledge, but its application is constantly being defined and made specific, based on the needs of each project. Evidence-based design is forward looking and creative, and more importantly, provides a basis for architects and management to have confidence in their design proposals. For this reason, research has become an important tool for healthcare architects. The question that arises is this: how should the academia respond to this greatly changed reality? How should architectural education evolve?

Before discussing education, the existing credentialling processes for healthcare architects in the US need to be understood and is described next.

1.0 CREDENTIALLING PROCESSES OF HEALTHCARE ARCHITECTS

For architects in the healthcare industry there are two credentialling paths. One is provided by the American College of Healthcare Architects (2023) and the other is Evidence Based Design Accreditation and Certification (EDAC), offered by the Center for Health Design. Before a discussion of these two, their nature and contents are described.

2.0 ACHA

The American College of Healthcare Architects (ACHA) provides board certification to registered architects who specialize in health care within the United States and in countries where NCARB reciprocal licensure can be obtained. Registered architects having licensure for three years and more than 6000 hours of healthcare experience in the last five years are eligible to sit for the examination. The process is overseen by an independent testing agency, in order to establish a professionally sound and legally defensible standard by which people can identify themselves as healthcare architects. The examination content is developed from a national survey of healthcare architects, and so exams vary within a fixed content outline. It consists of 120 multiple choice questions where 100 are scored and 20 are non-scored pretest questions. There are four 'domains' for testing and they are: (1) forces the drive the business of healthcare, (2) pre-design, (3) design, and (4) delivery and implementation. The weightage of the four domains is not the same and is shown in table 1 below. The time allocated for the examination is two and half hours. (American College of Architects 2023)

Table 1: Test domains and grade distribution for ACHA credentials. Source: (ACHA 2023).

Domains	**Number of questions**
Forces that Drive the Business of Healthcare • Economics and Reimbursement • Regulations and Accreditation • Healthcare Delivery Models • Technology • Staffing type and availability • Process Improvement/Lean Operations	15
Programming and Planning • Strategic Planning • Functional/Operational Narratives • Space Programming • Site and Facilities Master Planning	35
Design • Site and Facilities Design • Departmental Design • Detailed Design • Coordination with Engineering Systems.	35
Delivery and Implementation • Contracts • Construction Documents • Construction Administration • Project Implementation and Occupancy Scheduling • POE evaluation and Research Findings	15

It is quite clear that ACHA puts a high emphasis on Pre-Design and Design, as 70 percent of the questions are in these areas. Of additional importance, knowledge of research, or ability to conduct research is not tested.

3.0 EDAC

The second credentialling program called Evidence-Based Design Accreditation and Certification (EDAC), is for individuals who intend to demonstrate the ability to apply an evidence-based process to health facility design, including measuring and reporting results. The audience is more inclusive than ACHA's as it is aimed at a much larger group than only practicing architects. It includes architects, designers, healthcare executives, healthcare providers, academics, students, engineers, and product managers. This exam is administered by the Center for Health Design, an independent 501(c)(3) organization. The duration is two hours and has 110 multiple choice questions, of which 10 are not scored. (Center for Health Design 2023). The domains and weightage are shown in table 2 below.

Table 2: Test domains and grade distribution for EDAC credentials. *Source: (*EDAC 2023*).*

Domains	Percentage of the Exam
Evidence Based Design	25%
Research	25%
Project Set up and Pre-Design	15%
Design	15%
Construction and Occupancy	10%
Post Occupancy / Evaluation	10%

A quick comparison between the criteria of the two credentialling agencies reveals that 70% of ACHA's focus is on programming and design. On the other hand, 50% of the questions for EDAC are in research, and applications of research in the design process. It becomes 60% if Post Occupancy Evaluation is included.

Interestingly, this comparison brings out two important, and perhaps higher order aspects. Healthcare buildings are extremely complicated and therefore need experience and special 'expertise'. This seems to be the focus of ACHA. On the other hand, the notion of evidence-based design, which implies that each problem be tackled with up-to-date research knowledge and the ability to translate that knowledge to creative design, is the focus on EDAC.

4.0 VIEW FROM THE PROFESSION.

To get a better understanding of this 'expertise' and 'evidence' that is supposedly needed in healthcare design, as the two credentialing tests propose, a survey was carried out by the author. A questionnaire was created in Microsoft Forms and sent out digitally to practicing healthcare architects. The questions were set up in the context of what they expected from a newly hired architectural intern in their healthcare design practice. There were 26 questions, set in a 5-point Likert scale, and broadly categorized in four groups. These were: (1) basic understanding of healthcare facilities (figure 1), (2) professional preparation (figure 2), (3) disciplinary and interdisciplinary issues (figure 3), and (4) research (figure 4). Eighty-six respondents returned the survey; among whom 60% were healthcare architects and 26% were principals or partners in healthcare facility design firms. Responses to the questions divided in each category are shown in the figures below.

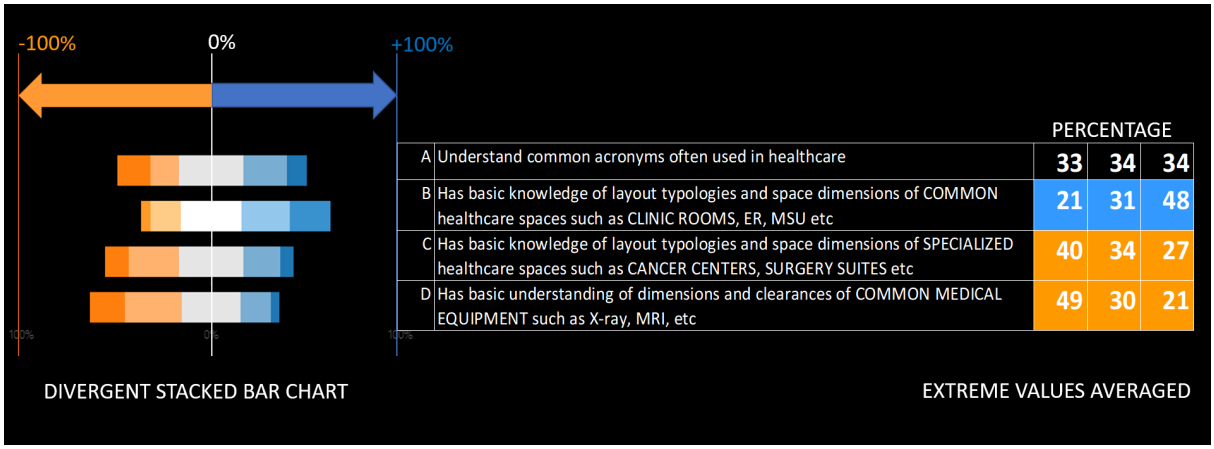
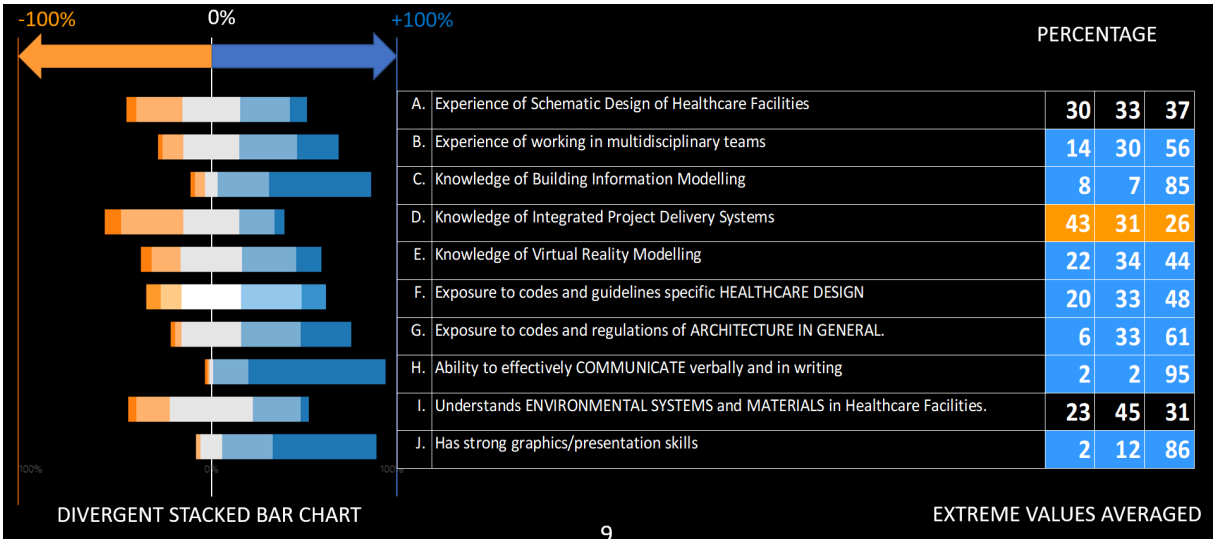
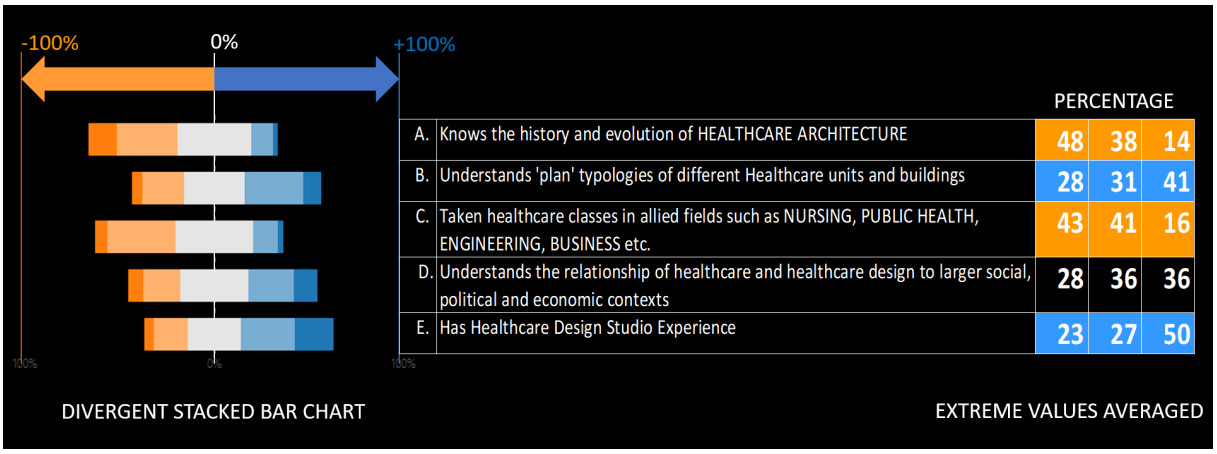


Figure 1: Questionnaire results of Category 1: 'Basic Understanding of Healthcare Facilities'. Divergent stacked bar on the left, actual questions in the middle, and percentages with extreme values added together on the right. Source: (Haq 2024).



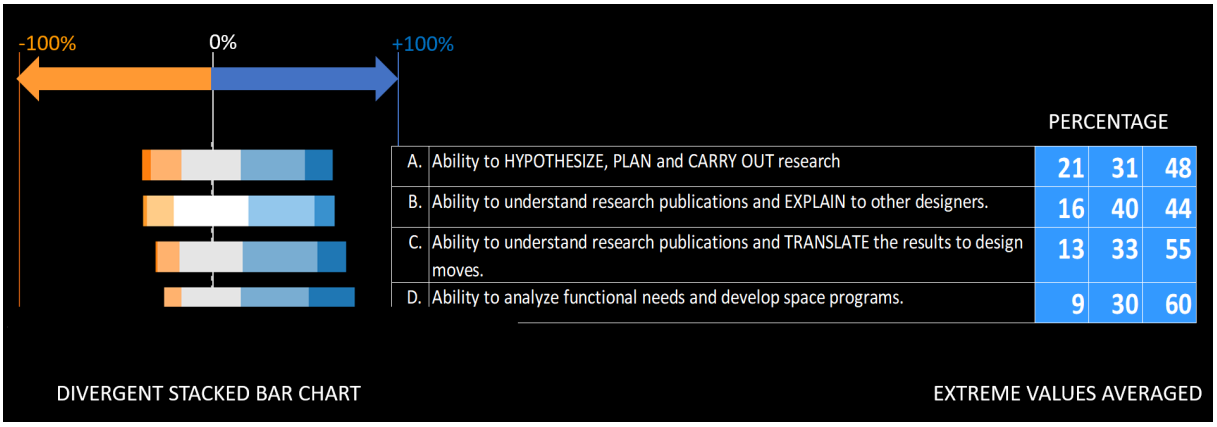
		PERCENTAGE		
A.	Experience of Schematic Design of Healthcare Facilities	30	33	37
B.	Experience of working in multidisciplinary teams	14	30	56
C.	Knowledge of Building Information Modelling	8	7	85
D.	Knowledge of Integrated Project Delivery Systems	43	31	26
E.	Knowledge of Virtual Reality Modelling	22	34	44
F.	Exposure to codes and guidelines specific HEALTHCARE DESIGN	20	33	48
G.	Exposure to codes and regulations of ARCHITECTURE IN GENERAL.	6	33	61
H.	Ability to effectively COMMUNICATE verbally and in writing	2	2	95
I.	Understands ENVIRONMENTAL SYSTEMS and MATERIALS in Healthcare Facilities.	23	45	31
J.	Has strong graphics/presentation skills	2	12	86

Figure 2: Questionnaire results of Category 2 'Professional Preparation'. Divergent stacked bar on the left, actual questions in the middle, and percentages with extreme values added together on the right. Source: (Haq 2024).



		PERCENTAGE		
A.	Knows the history and evolution of HEALTHCARE ARCHITECTURE	48	38	14
B.	Understands 'plan' typologies of different Healthcare units and buildings	28	31	41
C.	Taken healthcare classes in allied fields such as NURSING, PUBLIC HEALTH, ENGINEERING, BUSINESS etc.	43	41	16
D.	Understands the relationship of healthcare and healthcare design to larger social, political and economic contexts	28	36	36
E.	Has Healthcare Design Studio Experience	23	27	50

Figure 3: Questionnaire results of Category 3 'Academic, Disciplinary and Interdisciplinary Issues'.Divergent stacked bar on the left, actual questions in the middle, and percentages with extreme values added together on the right. Source: (Haq 2024).



		PERCENTAGE		
A.	Ability to HYPOTHESIZE, PLAN and CARRY OUT research	21	31	48
B.	Ability to understand research publications and EXPLAIN to other designers.	16	40	44
C.	Ability to understand research publications and TRANSLATE the results to design moves.	13	33	55
D.	Ability to analyze functional needs and develop space programs.	9	30	60

Figure 4: Questionnaire results of Category 4 'Research'. Divergent stacked bar on the left, actual questions in the middle, and percentages with extreme values added together on the right. Source: (Haq 2024).

The results provided some interesting perspectives of the profession about the requirements of a young graduate interested in healthcare architecture. Some of the relevant findings are:

1. Basic knowledge of layout typologies of common healthcare spaces is necessary, but knowledge of specialized healthcare spaces and equipment clearances are not. (Figure 1)

2. In terms of professional preparation, communication and graphic skills were favored by most of the respondents as was experience of working in multi-disciplinary teams (figure 2). Strangely, taking classes in allied disciples were not supported (figure 3). Regarding healthcare design, participants favored exposure to codes and guidelines (figure 2), perhaps to emphasize that critical navigation among them could be beneficial to good design. They also favored participation in healthcare studios (figure 3).
3. In the section regarding research, all questions received positive responses. The strongest response was that beginning architects needed the ability to understand functional needs and research publications to make design moves. Additionally, from the comment section of the questionnaire, the importance of shadowing/internship was detected.

It is important to keep in mind that the context of the survey was recruiting young architects in healthcare practice. This probably explains why some responses were unexpected. For example, knowledge of history and evolution of healthcare architecture, taking classes in allied fields such as nursing, public health, business etc., and understanding the relationship of healthcare and health design to larger social, political and economic contexts were not deemed relevant. On the other hand, the need for research in the skill set of young architects was validated. This supports a previous survey done by AIA

> where "86% of respondents indicated that a client had asked them for a research-based design or to research a specific question that would impact the design. 98% of respondents indicated that they found using evidence allowed them to achieve better design outcomes. 71% of respondents indicated that their firm had engaged a consultant (academic or other outside expert) to help with an evidence-based design project." (Pentecost, Haq, and Byrd 2016, pp 116)

The three findings from the profession, described above, is instrumental in discussing healthcare design teaching, and this is discussed next.

5.0 HEALTHCARE TEACHING

Healthcare design teaching has existed as post professional programs in several US universities. However, making it part of the professional architecture program is a relatively new initiative, and arguably is in response to the rapidly increasing scope of healthcare design and construction, and the change in mindsets towards responsible design. Clemson University has had a long-standing Master of Architecture professional program that focuses on healthcare. It started as the Healthcare Facilities Planning and Design Studio in 1968, and has since grown to a full-fledged NAAB accredited M.Arch degree. (Allison 2022). Today some schools offer post professional degrees (MS, PhD) in healthcare design, and some have faculty with an interest in healthcare who teach a few courses within the main curriculum. For professional M.Arch students who might want to prepare themselves to get into the expanding field of healthcare design, there are only six schools in the US that offer certificates as part of the MArch program (see table 3).

Table 3: Comparison of courses of six US schools of Architecture that offer a certificate in Health Care Design. Source: (Haq 2024).

Institution	**Texas A & M**	**Kent State**	**Ball State**	**Texas Tech University**	**University of Kansas**	**University of Illinois at Urbana-Champaign**
Name of Program	*Health Systems and Design*	*Health Systems and Facilities Design*	*Planning and Design of Healthcare Environments*	*Healthcare Facilities Design*	*Health and Wellness Architecture*	*Health and Wellbeing*
Credit Hours	16 hours	12 hours, online	12 credits, online	12 credits	15 credits	22 credits
Information source	https://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/architecture/health-systems-design-certificate/#programrequirementstext, accessed 1/23/2024	https://www.kent.edu/caed/graduate-certificate-health-systems-and-facilities-design, accessed 1/24/2024	https://www.bsu.edu/academics/collegesanddepartments/online/academic-programs/graduatecertificates/healthcarefacilitydesign, accessed 1/24/2024	https://catalog.ttu.edu/preview_program.php?catoid=17&poid=12286&returnto=1700, accessed 1/24/2024	https://arcd.ku.edu/certificate-health-wellness-architecture, accessed 1/28/2024	https://arch.illinois.edu/programs-applying/program-areas/health-and-wellbeing/ accessed 5/8/29024

RESEARCH	Health Design and Research (3)	Evidence Based Design in Healthcare (2)	Evidence-Based Design in Healthcare Settings (3) Understanding and Practicing Research in Healthcare Design (3)	Evidence Based Architecture (3)	Evidence-Based Design Research Theories and Methods (3)	Advanced Research in Environment, Architecture and Global Health (4) Advanced Applications in the Built Environment, Architecture and Global Health and Well-Being Social and Behavioral Research in Designed Environments
PATIENT POPULATIONS		Environments of Care and Patient Populations (2) Patient Safety and Systems Thinking (2)	Health Environments for Patient Populations (3)			
ENVIRONMENTS AND SYSTEMS		Environmental Systems and Materials in Healthcare (2) Healthcare Facilities (2)				
STUDIO				Architecture Research and Design (6)	Health & Wellness Capstone Studio (6)	Architecture Graduate Studio (6)
INTERNSHIP					Health & Wellness Internship (6)	

OTHER COURSES	Seminar (1)		Legal, Ethical, and Safety Issues in the Healthcare Industry (3)		Architecture of Health (3) Directed Readings on topics related to Health and Wellness Design (3)	Soc/Beh Factors in Design Gender & Race in Contemporary Arch Special Problems in Health and Wellbeing
MULTI DISCIPLINARY ELECTIVES	Electives. Different disciplines	Electives. Different disciplines		Electives from different disciplines		One elective from another discipline

Certificate programs are a set of courses, usually between 9 to 15 credit hours, that a student can take to build particular skills or knowledge. Generally, they are open to students enrolled in a larger program, or they could be taken as a stand-alone program for any student who wants to participate.

A comparison of the six certificates in the six schools provides an interesting picture of how the teaching of healthcare design is considered by each. (see table 4). First, all schools consider research as indispensable, and they all have at least three hours of research or evidence-based design. Multi-disciplinary electives seem to be the next important aspects as four schools offer them. These courses are drawn from nursing, business, public health, psychology etc. Healthcare studios where health is addressed through design exercises is taught in three schools. Understanding of patient population is also focused in two schools.

Table 4: Relative importance of various aspects of healthcare design in different schools. Source: (Haq 2024).

SCHOOLS	**1**	**2**	**3**	**4**	**5**	**6**
RESEARCH						
PATIENT POPULATIONS						
ENVIRONMENT AND SYSTEMS						
STUDIO						
INTERNSHIP						
OTHER COURSES						
MULTIDISCIPLINARY ELECTIVES						

6.0 DISCUSSION

The conditions today regarding healthcare and healthcare facilities design call for a radical transformation in design thinking where the ability to interact with technical knowledge and scientific evidence is necessary. For this, architects need to be trained in both design and research. This is the biggest challenge in educating architects for a career in the evidence-based healthcare sector. Design is inclusive in the sense that designers must deal with many complexities simultaneously, while research is exclusive in the sense that researchers find ways to ‘control’ or eliminate extraneous variables. While one is creative, the other is systematic. Thus, the mindset required for these two activities is very different, yet this ‘integration’ is what this sector demands and what educators strive to achieve. Healthcare design needs people who can use both sides of their brains to integrate creativity and logic. This is not easy.

Regarding research, an important question to be answered is: should architects be producing research, or should they understand and use existing research? Hamilton (2004) has argued that there are four kinds of architect-researchers, or evidence-based practitioners. Level one practitioners know how to find evidence and how to read and understand research publications; and so, they carefully base their design on available peer reviewed literature. Level two practitioners hypothesize expected outcomes of their designs and measure results. Level three practitioners do all that level two practitioners do, and in addition they report their results publicly to inform others beyond the firm and client. Level four practitioners carry out all the above and publish in peer reviewed venues. Thus, their research methods, analysis etc. are scrutinized through the process of peer review. Teaching research to architects in the professional program might be limited to teaching them how to find, evaluate, select, and read research articles with sufficient rigor so that they can translate research findings to design moves. In other words, professional architectural education should teach graduates to be level one evidence-based practitioners. Post professional education is the place where interested health care designers might learn to be level two, three and four.

On another note, healthcare facilities are very complex buildings.

> The healthcare environment is a work environment for the staff, a healing environment for patients and families, a business environment for the provision of healthcare, and a cultural environment for the organization to fulfill its mission and vision (Center for HealthDesign 2010, 01).

It is also a place that houses high tech equipment that are constantly evolving and reducing in size, a building type that is controlled probably by more codes than any other type, a building type that consumes enormous amounts of energy and emits great quantities of greenhouse gases, and one with high water use intensity and a producer of enormous quantities of waste. To deal with any one of these issues requires specialized training and experience. So, it is not a surprise that the two credentialling agencies test very different aspects of healthcare design skills. Similarly, different architecture schools have taken on different models in designing their curriculum, perhaps making the best of the expertise that is available in each university.

There seems to be little doubt that the future of healthcare design will be collaborative across disciplines and evidence based. As such, collaboration skills, interdisciplinary understanding, and research seem to be the three most important skills to be taught to architecture students aiming for a career in healthcare design. They need to 'speak the same language' as physicians, nurses, administrator, and other groups, and should understand their priorities. With the same logic, creating better healthcare environments requires those 'other' disciplines to understand the value and effect the environment has in various healthcare outcomes. Credentialling of those professions also should have a component of environmental possibilities and effects. For architects, credentialling efforts must evolve to include interdisciplinary skills, collaboration, and research.

This paper has discussed the evolving nature of healthcare facilities design, the criteria of credentialling and different educational models for professional education available in the USA. It has emphasized interdisciplinary understanding, collaboration skills and research acumen as essential skills for healthcare architects. The credentialling efforts also need to be revised to include these qualities, and credentialling of allied disciplines should also incorporate a component of environmental effects in healthcare.

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Public Space Design enabled by Artificial Intelligence Generative Tools

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ABSTRACT: This paper discusses the integration of generative artificial intelligence (AI) tools in the conceptual phases of the design of a public space. It raises the question of how AI tools can enhance the design process and how the integration of AI tools in a design process may affect the interactions between architects and clients. The investigation uses a collaborative project between academia and a major art institution to transform a vehicular street into a pedestrian event space supporting art and community programs.

The methodology was framed around generative AI platforms, such as Dall-E 2, Midjourney, BlueWillowAI, DreamStudio, Lexica, and Stable Diffusion utilizing both text-to-image and image-to-image functionalities. The approach followed the reiterative process of developing design variations, evaluating outputs, identifying desired traits in imagery/designs, and exploring new possible designs based on desirability. The study demonstrated (1) accelerated idea formations in the early stages of the design process and (2) an enhanced ability to communicate with a broad audience.

KEYWORDS: public space, artificial intelligence (AI), design education

INTRODUCTION

Generative artificial intelligence (AI) is a rapidly advancing technology transforming design practice and education (Newton 2021). How AI technology interacts with human creativity—whether through collaboration, reliance, or mutual dependence—will define the conversation about AI in the upcoming years (Newton 2019, Huang et al. 2021). This necessitates the formulation of strategies for creative partnerships and joint authorship with AI.

This paper demonstrates an approach for an AI-enhanced architectural design process that empowers students while letting them maintain intentionality and authorship. Specifically, this paper is investigating (1) how AI applications can change a design process (2) how AI can impact design education, and (3) how AI applications can impact the interaction between architects and clients.

The research uses an urban project as a case study and framework to test the potential of AI applications in terms of enhancing design processes, streamlining creativity, and engaging a larger community. Through a series of experiments that test AI applications from context analysis and idea generation to the refinement of the design, the research intent is to establish best practices for AI-facilitated design processes. The project also identifies the advantages and disadvantages of AI tools while demonstrating a strategy for applying AI tools in practice and architectural education.

1.0 TECHNOLOGY CONTEXT

Applications of generative AI in design and visual arts are a relatively recent phenomenon. Several researchers explore the analysis and creation of two- and three-dimensional designs (Newton 2019) considering particular cultural contexts and identities (Huang et al. 2021). AI research in architecture addresses Useful Daylight Illuminance (UDI) optimization for buildings at an urban scale (Canli et al. 2023) or building frameworks to design energy-conscious buildings (Aman et al. 2023). Text-to-image applications can also be used in urban planning to engage a larger community in new ways in a design process, synthesize emotional responses of citizens in a design process (Riether & Narahara 2023) or allow all project stakeholders, both professionals and the public to directly participate by visualizing their design proposals for future urban landscapes (Mugita et al. 2023).

However, the field of architecture has not benefited from AI developments to the same degree as other disciplines (Özerol et al. 2023). This points to a slow adoption of these new technologies in creative disciplines. The emergence of stable diffusion tools is significantly changing the use of image-based AI in architecture. This is evident in some recent studies that apply AI in various curricular frameworks (Dortheimer 2023). Many of these studies operated semantically evoking poetic texts, such as Italo Calvino's "Invisible City". Others see AI technology as a one-for-one replacement of conventional design processes, not as a form of creative partnership. The question of intentionality and agency is rarely investigated (Terzidis 2023), yet it is fundamental to the future use of AI tools in design and particularly the role clients and other non-designers play in the formation and selection of design concepts. AI-driven design processes may be of a more collaborative nature, which will be addressed in the result section of this paper.

2.0 PROJECT CONTEXT

The topic of the studio project was the redesign of a Public Space for the Arts for the *Kunstmeile Krems*. Forty-three miles west of Vienna, Krems is located at the Danube River at the gate to the UNESCO World Heritage site Wachau, a well-known wine region in Austria. The town is rich in history with its cultural and architectural growth peaking during the Renaissance and Baroque periods. Today, it is the center of higher education and culture in the Lower Austria region. The *Kunstmeile Krems* is an umbrella organization for several museums, galleries, art foundations, and cultural events such as music festivals. Most of the venues are located along the Steiner Landstraße, currently, a one-mile-long monotonous two-lane street with street parking that connects the urban centers of Stein and Krems, two towns that are characterized by their medieval structure and that have during industrialization merged into a single urban entity (Figure 1).

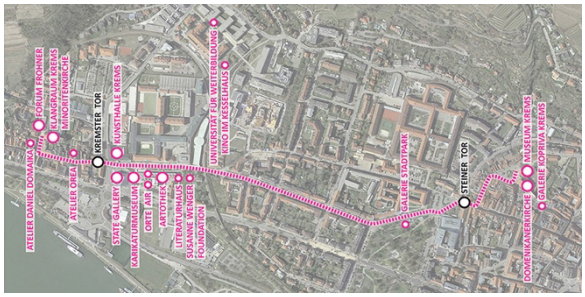


Figure 1: Art Institutions affiliated with and located on the *Kunstmeile Krems*. Source: (Gernot Riether, the author 2024)

The project was conducted within an architecture design studio comprising 16 upper-year undergraduates (B.Arch) during the summer of 2023. The first part of the studio (3 weeks) was held at NJIT's campus in Newark, and the second part (3.5 weeks) took place at the actual site in Krems, Austria, where the studio was set up in the Artist of Residence Program (AIR), located directly at the site of the project. This living and working arrangement allowed students to observe the site over an extended period while they were refining their projects. Due to time constraints, the project used tools that can expedite design ideation and communications, which included generative AI tools, image processing (Adobe), and rapid 3D modeling software that facilitates free-form designs (Rhinoceros 3D). Between the time in Newark and Krems, students went to Vienna for a week where they toured many examples of public spaces, relevant to the studio's project. One of the spaces examined more closely was the Museums Quartier (MQ), a public space shaped by a diverse array of cultural organizations that has in recent years transformed cultural activity in Vienna by attracting a growing number of cultural initiatives to its surrounding area. (Roodhouse & Mokre 2004)

3.0 CASE STUDY - FRAMEWORK

3.1. Project goals

Goals for the redesign of the *Kunstmeile Krems* were established in discussions with the stakeholders of the project, which included directors, curators, and artists from the institutions of the *Kunstmeile Krems*, city officials, and residents of Krems and Stein. The following goals were agreed upon: (1) Transform a part of the Steiner Landstraße into a public space that spatially connects the art venues of the *Kunstmeile Krems*; (2) Develop a spatial identity for the *Kunstmeile Krems* that will facilitate wayfinding and place-making (public readings, performances, workshops, and outdoor exhibitions); (3) Integrate programs that promote social interactions by introducing design-quality urban furniture, sun shading through greenery and shading devices.

To achieve these goals additional strategies were identified: (1) The development of modular action platforms for temporary and permanent initiatives by the institutions located on the *Kunstmeile Krems*; (2) The transformation of sealed surfaces currently used for streets, parking, and sidewalks into permeable, green spaces that reduce heat island effects and mitigate stormwater runoff; (3) The Reduction of traffic on Steiner Landstraße by prioritizing pedestrian and bike use. (4) The development of strategies for changing the traffic pattern to improve the connection of the *Kunstmeile Krems* with remote parking and the town's train stations.

3.2. Course structure

The studio was structured into four main parts that will be described in detail below: (1) Context and Site Analysis, (2) Conceptual Explorations, (3) Contextualized Concepts and (4) Schematic Design. Each of these parts was structured around the use of AI applications. During each of these milestones, meetings and visits were conducted with stakeholders to learn about the institutional needs and gain inside perspectives. In addition, reviews were set up that provided opportunities to engage with the residents, the artist community, and city officials (Figure 10).

3.3. Methods

The studio facilitated an open experimentation culture encouraging students to adopt a wide range of generative AI tools and models. These included Dall-E 2, Midjourney, BlueWillowAI, DreamStudio, Lexica, and Stable Diffusion. Some students would run implementations of stable diffusion locally but a majority used available services, free or paid. Initial work was done utilizing text-to-image functionality with some image-to-image in combination with text prompts. The methodology relied on the reiterative process of developing design variations, evaluating outputs, identifying desired traits in imagery/designs, and exploring new possible designs based on desirability. Prompt engineering strategies involved contradictory requirements and ambiguity in the early stages to ensure a diverse and unprescribed set of solutions. In late design process stages prompts, and occasionally in/out-painting, became more focused and prescriptive to maintaining chosen traits/features over generations of variations.

4.0 CASE STUDY - RESULTS

In each of the 4 parts of the design process students explored different strategies to utilize AI applications in different ways. In the context analysis students developed prompts to match a specific outcome, in the conceptual phase students developed prompts to provoke surprising results and in the final phase of the project AI applications were used to create variations.

4.1. Digital wachau: cultural context explorations

As part of the site analysis and to develop a good understanding of the unique characteristics of the Wachau region students were asked to develop prompts that described the Wachau Valley without using the word “Wachau” and compare the resulting images to pictures of the actual valley. Early prompts such as “wine region in Central Europe” sometimes got close but triggered a discussion about how images would compare to the Rhine Valley in Germany or Tuscany in Italy. Successful prompts were combining characteristics of wine terraces with crystalline rock formations, hills, rivers, medieval urban structures, and elements of Renaissance and Gothic architecture.



Figure 2: Digital Wachau, AI-generated images representing what DALL-E model considers central European historical context. While closely showing the landscape and urban characteristics of the Wachau Valley, the prompts were rather general (prompt: “scenic overlook over a vine valley with castles and ruins and urban architecture” (far left) and prompt: “castles and ruins and urban architecture with pedestrian on cobblestone roads” (left) Source: (Loc Nguyen 2023), Capturing the mood and environmental aura of the region with an expressive image style. Prompts: “Wachau Valley, alongside river, populated with people, small houses at far distance with terracotta roofs, green landscape, town church” (right) and “Wachau Valley at night, illuminated with streetlights, town homes with terracotta roofs, town church, town reflected on Danube River” (far right) Source: (Karla Vasquez 2023).

This exercise also illustrated how generative AI can synthesize a diverse set of qualities to produce images with identity and authenticity. The resulting images were evaluated against the actual characteristics of the valley. The more feedback students received by using AI tools the more detailed and precise the prompt became. A close match of the prompt outputs to the actual Wachau Valley scenery speaks to the visual and landscape characteristics between a broader range of locations that follow a similar spatial continuum. This is evident in Figure 2 when compared to the left and far left to the images on the right and far right where the locality was specifically included in the prompt. Students also experimented with various visual representation styles (Figure 2) to convey a more ephemeral and elusive feel for the region. This initial exercise achieved two objectives by allowing students to (1) explore cultural and scenic genius loci of the Wachau Valley and (2) develop preliminary understanding and skills associated with generative (text-to-image) AI. The former was particularly important since this phase of the course was conducted remotely. Additionally, these AI explorations were an important element of student immersive experiences with the local heritage.

4.2. Conceptual explorations

From the previous exercise, students gained the ability to develop prompts and produce expected outcomes. Since they were free to experiment with diverse AI platforms, they also learned how to navigate various stable diffusion models and how to apply them for the desired effects as seen in stylized imagery. This broader evocative use of AI-generated imagery was a critical part of the creative layer of the design process. Since the goal of the studio was to develop highly engaged and experientially memorable (iconic) public spaces students conducted case studies and identified important precedents. However, unlike in the traditional design process where precedents serve as a springboard to design explorations, here the precedents were used to produce text-based descriptive prompts that were fed into AI (Figure 3).



Figure 3: From precedents to mental and textural notes, and to AI prompts. Transcending precedents and exploring design space of prompts: “pedestrian street, with lots of modern urban furniture, people interacting with one another, wooden pavilion” (left) and “pavilion filled with mirror and glass on pedestrian street, people interacting with one another, vivid lights reflecting of pavilion” (right) DALL-E. Source: (Karla Vasquez 2023).

The driving keywords of this image series were sunshade, stained glass, vivid colors, and hanging mirrors, which respond to the key design goals identified earlier. This approach allowed students to develop the vocabulary necessary to communicate design intent. It provided additional layers of translation and abstraction facilitating the transcendence of the original precedents and producing novel outcomes. This can be seen in Figure 4 where visual and evocative logic (abstracted creativity) is privileged over technical and constructability, which is critical in the early stages of the design process. While prompts emphasized visual and experiential qualities, they also pursued the key project goals, such as interactive and immersive engagements, and family-friendly spaces.



Figure 4: Explorations of public art in public spaces. Prompts included: “contemporary art installation that transforms a road into a public plaza into a realm of immersive experiences, sensory wonder, avant-garde design, creativity and engagement, tactile experiences, playful, family-friendly, both striking and harmonious, captures the essence of urban life” (left) and “Create a digital representation of an interactive contemporary art installation set in a public setting that showcases a future vision of a multifunctional and interactive public space in the style of Gabriel Dawe” (right). Source: (Isabella Gil 2023)

An important part of the conceptual explorations was the development of variations, the selection of promising outputs, and the continuation of selected design alternatives through subsequent variations (Figure 5). This allowed students to explore a broader class of design solutions in effortless yet focused ways and gave students a deeper insight into tectonic and programmatic solutions possible. This can be achieved by (1) maintaining the same prompt while changing the seed, (2) slight variation to the prompt, (3) using the output image as an input partially weighted with the changed prompt, or (4) using in-painting and out-painting tools. This range of techniques allows for a close and/or localized control of the images. Guiding variations is one of the most important steps in the AI-enabled design process as it brings back the agency and authorship to designers, and in this case to students. It also facilitates the development of critical visual thinking and mitigates the designer’s fixation with initial AI outputs, also known as automation bias (Zarzycki 2023).



Figure 5: Variations as an exploration of possible design space. Source: (Albina Zhaku 2023).

4.3. Contextualizing concepts

Once a broad array of idealized designs was formulated, students were asked to evaluate these conceptual designs for their fit with program, project goals and the immediate urban context. To address contextual relationships students used site images (Google Street View) and fed them into an AI platform with prompts describing social and functional requirements, such as seating or shading. Combining diverse and usually competing parameters resulted in images that were sometimes prosaic but more often inspiring and meaningful.

At this stage, the overall feel and mood of the image were deprioritized, and the focus was shifted to details and fidelity. Students followed a similar exploration, variation, and refinement process as outlined in the section above. Since one of the goals of the project was to transform a street into a pedestrian space, elements such as parking, traffic signs, and cars were removed from the Google Street View. Using the same base images students conducted three types of studies:

Experiment 1: Use prompts that describe the project such as “Public Space with seating and shading” Part of the prompt also had to define the type of outcome “eye-level view of an outdoor space with many pedestrians, highly detailed, photorealistic, V-Ray rendering.”

Experiment 2: Use a prompt without terms that directly describe functions or the type of spaces such as “Public space with a café” but instead trigger surprising ideas for a new type of public space by describing the qualities of the space such as “colorful, happy, immersive, dreamlike space” describing qualities from the site such as “wine terraces or floodplain forest” and add descriptions of artwork or artists’ names such as “Media art, James Turrell.”

Experiment 3: Add elements to the prompt that are entirely foreign to the prompts from the second round such as “soap bubbles” These prompts should avoid words that describe architectural or urban typologies such as “insect wing” or “rolling hills.” At the same time, students were asked to consider negative prompts to filter out undesirable elements, such as “cars, ugly, sad.”

These experiments allowed students to progress work from defined and prescriptive to open-ended and imaginary transcending obvious design associations and solutions. The range of outcomes from these three experiments (Figures 6).



Figure 6: A design scheme showing a full conversion from the vehicular to pedestrian street and enhancing it with seating, greenery, and water features. (left) Source:(Josh Pledger 2023). A high-energy event space with pavilions and street furniture. Prompt: “nighttime cinematic, surreal origami public space, surreal public plaza space, futuristic, colorful, lights, cinematic, paper, fun, interactive, origami pavilions, professional color photograph, immersive experiences, colorful spectrum, lit up ground, projections, technology, futuristic, style of Daan Roosegaarde“. Source: (Layla Neira 2023). Umbrella-like structures provide shading and visual interest. Prompt: “professional color photograph, full with large scale people, awe-inspiring anamorphic art, realm of interactive experiences and sensory wonder, outdoor, high pedestrian transit, dreamlike world, distorted geometry, unexpected juxtapositions”. Source: (Isabella Gil 2023).

4.4. Schematic design

The designs from the previous exercise were grouped based on themes associated with design scenarios’ materiality or formal effects. Then, students discussed the potential of each of the themes and interpreted the AI perspectives against functional and practical requirements. Based on these discussions four themes were selected and four teams formed.

Arriving at the site it became clear that working with Google Street View images made students underestimate the scale of the site. Projects required adjustments to meet the actual scales as seen in the comparison between Figures 6 and 7. There was also a similar situation with several programmatic requirements. Students’ experience of the site on a hot summer day translated quickly into an increase of shading devices in their projects.

The initial AI images were translated into viable 3D environments that responded to functional requirements while maintaining the characteristics and identities that they evoked. Plans (Figure 7) were used to resolve key functions of the projects such as seating and shading. Plan drawings were also used to evaluate traffic flows, accessibility, and location of common facilities, such as information booths, bathrooms, or private tenant spaces (restaurants, café, bars, museum stores, and galleries). This part of the process took most of the time on site, as expected, as AI imagery was effective in stimulating initial creative thinking but still similar to those ‘napkin-like sketches’ needed to be fully thought through and resolved. However, having multiple variations of design proved to add to the flexibility of the refinement stage. While developing schematic design continue using AI tools for variations that were later used as more finalized renderings. In this stage, students used the image-to-image feature, which allowed them to maintain the overall character but provided imagery that was articulated differently in terms of mood, detail, and materiality (Figure 8). All four projects followed the same process: DON-AU (Figures 7), TERRACES (Figure 8),

URBAN BASKET (Figure 9), and SONNENDACH (Figure 9), with titles referencing initial AI prompts (with the word ‘Au’ representing floodplain forest in German).

DON-AU (Figures 7) used prompts that combined fabric effects, the vein structure of local insect wings to create lightweight fabric trees growing from a landscape of seating and plants that was generated by a prompt that combined landscape effects of meadow and floodplain forests that occupied the site before the Danube River was regulated. The fabric trees were developed into shading systems that could also be used as surfaces to project information from the museum’s exhibitions.



Figure 7: DON-AU: The continuation of the umbrella-like structures with added programmatic elements, such as greenery and gathering places, Rendering and Site Plan of final project. Source: (Isabella Gil, Valeria Gomez and Karla Vasquez 2023).

TERRACES (Figure 8) used prompts that described the terraced vineyards of the Wachau Valley. The terraces were developed into a system for seating and shading. The terraces were shaped for people to mingle and accommodate different scales of groups of people and arrangements that could be utilized for events by the bordering art organizations such as public readings, screenings or public debates. The terraced shading system also acted as planting pods and was optimized to maximize the green surfaces in the public space.



Figure 8: Using Image-to-image AI applications to generate variations for final renderings, Terraces. Source: (Angela Evangelista, Kennedy Pfeifer, Mona Pandaya 2023).

URBAN BASKET (Figure 9) used prompts describing the woven structure of a Zistel, a traditional basket made from osier stake in this region to harvest apricots. The woven structure was used to integrate seating and shading devices into a single complex urban furniture that could vary in size to accommodate social gatherings of different sizes.

SONNENDACH (Figure 9) divided the public space into horizontal layers reminiscent of the time before the Danube River was regulated and this area was regularly flooded. The layers function as a large roof that interacts with the existing trees and provides shade for the entire public space and projects shadow patterns at different scales onto layers below. Other layers maximized green spaces or served as seating devices.



Figure 9: Urban Basket (left) Source: (Project by Project by Angelica Valinoti, Loc Nguyen, Mateo Fuentes 2023). Sonnendach (right) Source: (Project by Albina Zhaku, Josh Pledger, Layla Neira, Dillon Imes 2023)

All projects emerged from the AI images transforming the streetscape into a pedestrian place with different identities. Each of the projects successfully responded to functionality by creating a space to socialize and a space open to cultural activities, such as public readings, performances, workshops, and outdoor exhibition spaces. All projects also responded successfully to requirements of un-sealing surfaces and maximizing green spaces.

TERRACES for example uses the shading device as large planting pots (Figure 13). All projects could have developed further to provide additional programs, such as restaurants, café, or bars to activate the space all year round.

4.5. Client interactions

Kunstmeile Krems served as the main client. Other stakeholders included museum and gallery directors, curators, and artists, the residents of Krems and the Local Government Officials and the Public. During the first online meeting with the CEO and other representatives from the *Kunstmeile Krems*, students presented AI renderings of 50 different future public spaces. All images were produced within the first few days of the studio. Images were selected based on the responds from stakeholders and ideas that students saw in them. Traditionally an architect would show abstract diagrams or sketches at a first meeting with the client. This presentation allowed for the client to evaluate if they could identify with the characteristic or mood of an image rather than how the architect responds to function in a floorplan. It allowed for the client to interpret the image their own way and find new possibilities in the images that the student has not thought about. The discussion was used to narrow down the number of images. This initial meeting was also used to gain insight on the recent history of the site and to find out what the needs of the stakeholders and the larger community are.



Figure 10: Review after the first week on site with representatives from the *Kunstmeile Krems*, Günter Herz, Head of City Planning and Elisabeth Kreuzhuber, Municipal Councilor. Source: (Gernot Riether, the author 2023)

Once the studio relocated to Austria students visited the museums and galleries that make up the *Kunstmeile Krems* and asked curators and museum directors about their ideas and needs for a public space in front of their venues. After one week at the site the studio presented work in progress. This time to representatives from the *Kunstmeile Krems* and to the Head of City Planning from the City of Krems (Figure 10). The use of AI generated perspectives made it easy for an audience that were not architects to relate and understand the different projects. AI tools were used to generate multiple variations for each project (Figure 5), which provided choices. Projects were presented as systems that could be used to only transform small parts of the site or take over the entire site. Instead of presenting a final project the presentation led to an open-ended discussion about new opportunities. Aspects that were discussed were permanent versus temporary programs, venues in the public space by private tenants such as restaurants, café, bars and surfaces that could be unsealed and transformed into natural landscape.

During the last week on site each team refined their projects and developed another presentation (Figure 7). ORTE, the Architecture Center of Lower Austria invited the public to join a final review of the studio. Stakeholders were excited to see how each of the projects created spaces that connect to art and context and have the potential to draw people to the art venues. Projects also received very positive feedback regarding their unique spatial identity for the *Kunstmeile Krems*. But most importantly the studio had successfully helped to connect different stakeholders, trigger a discussion between stakeholders and city officials and generate an appetite to see more.

CONCLUSION

The paper presents generative AI-driven alternatives to the conventional design process with a focus on fast-paced idea generation and close interactions with a broad range of stakeholders. It demonstrates the requirement for a new form of literacy, a shift in thinking from sketch to text. It also demonstrates a short learning curve and quick technology adoption by both students and clients as well as the ease of interacting (interface) with new modes of creativity and high-quality of produced outcomes. Seeing how AI tools change the pace and frameworks of conversations between architects and clients also raised questions about the authorship and intentionality of designs.

This case study also provides an opportunity to evaluate curricular methodologies in architecture education, especially for the design studio. Generally, the AI-generated work outperformed other visualization and conceptualization skills students brought into projects. Understandably, this helped to garnish enthusiasm for the toolset and projects. Prompt-based interface (text-to-image) with image-to-image refinements also changed the

way one would think about the progression from abstract to more refined ideation, the use of evocative representations, and context-minded solutions. It changes the types of presentations, requires new formats of interaction, and provides new opportunities.

Students also discovered limitations of generative tools that may impede creativity: an ease of outcomes may reduce an inquisitive drive resulting in early gratification without a transformational use of creative/design tools. Other challenges may include the difficulty of transitioning from high-quality and high-fidelity AI-generated imagery to 3D models and conventional modes of architectural representation, which initially may feel under-defined. Finally, it is worth future studies to better understand emerging relationships between an image, a drawing, and a 3D model, and how this relationship be affected by generative AI.

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Designing Atmospheres: The Pedagogical Approach of Peter Zumthor

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ABSTRACT: How can the design of atmospheres be taught? How can it avoid the vagueness and superficiality at times associated with this concept? This paper describes the pedagogical approach of an architect for whom atmosphere is a central concern: Peter Zumthor. While his architecture is well known, little has been written about his teaching at the Academy of Architecture – Università della Svizzera italiana (USI-ARC) between 1996 and 2007. The paper analyzes the documents of Zumthor's teaching and highlights three aspects of designing atmospheres: analyzing and reproducing emotionally significant memories of atmospheres, documenting observed atmospheres, and imagining and building atmospheres. Lessons for the future of architectural pedagogy include: working with 'real' construction materials to develop an awareness of their sensory qualities, using personal memories and experiences as starting points for design, forming a clear intention for atmosphere and material qualities at the beginning of the design process, and designing atmospheres not merely as aesthetic experiences, but as backgrounds for social life.

KEYWORDS: Atmosphere, materials, memory, imagination, pedagogy

INTRODUCTION

Architectural education is continuously evolving in order to prepare students better for the changing realities of professional practice – to work within them, to critique them, and to improve them. These changing realities include projects of increasing complexity, the climate emergency, social justice challenges, and evolving technologies and digital practices (Sanderson and Stone 2022). The role of the architect is also shifting from a designer or master builder to a coordinator of multiple efforts. Approaches to architectural pedagogy are adapting, for instance with live projects, community-engaged design-build studios, and complex, real-world design assignments (ibid). However, design teaching still often emphasizes the talent of the individual designer and the formal, artistic aspect of architecture, overlooking the collaborative and social dimensions (Salama 2021).

The design of atmospheres may at first seem to perpetuate this overly artistic approach to architectural pedagogy. Atmosphere has been described as an ephemeral and theatrical sensuous surface effect that architects show in their drawings through glowing or blurred edges, but that cannot realistically be predicted or controlled (Wigley 1998). Its appeal to the senses can seem to avoid intellectual and critical engagement with buildings (Wegerhoff 2016), and to overlook contemporary social issues (Campbell 2004). However, this paper argues that the design of atmospheres is concerned with tangible material qualities, that the pre-reflective experience of sensuous atmosphere supports rather than opposes critical engagement, and that atmosphere is an inseparable part of the social dimension of the built environment.

The relevance of atmospheres in architectural pedagogy is demonstrated by examining the work of an architect for whom this concept is a central concern: Peter Zumthor. While his architecture is well known, little has been written about his teaching at the Academy of Architecture – Università della Svizzera italiana (hereafter referred to as 'Academy' or as USI-ARC) in Mendrisio between 1996 and 2007, with the exception of recent scholarship by Brazilian architect and scholar Rafael De Conti Lorentz (2021). An examination of the records of Zumthor's teaching in the Academy archives reveals approaches to teaching the design of atmospheres that can enrich the future of architectural pedagogy.

This paper is structured in three sections. The first introduces the notion of atmosphere in the built environment. The second introduces Zumthor's design teaching at the Academy, describing two core principles of his pedagogical approach – phenomenology and what he calls "scientific intuition" – and draws parallels between these principles and his architectural practice. The third section describes selected assignments that Zumthor gave his students, presenting three aspects of designing atmospheres: (1) remembering atmospheres, (2) observing atmospheres, and (3) imagining and building atmospheres. The conclusion formulates lessons for architectural pedagogy.

1.0 ATMOSPHERE

Atmosphere is that which relates the perceiving subject with the sensory qualities of the environment. German phenomenologist Hermann Schmitz (1928 – 2021) describes atmospheres as "affective powers of feeling, spatial bearers of moods" (Böhme 2017, chap.1). For instance, the atmosphere of a room may be oppressive, and that of

a valley may be joyful. Schmitz influenced German philosopher Gernot Böhme (1937 – 2022), who defines atmosphere as that which "mediates objective factors of the environment with aesthetic feelings of a human being," or with one's "bodily feeling in that environment" (Böhme 2017, Introduction). It is both objective and subjective. For example, in stage design, a specific atmosphere is created by using particular sounds, lighting, materials, colours, objects, signs, and spatial arrangements (Ibid).

Atmosphere plays a role in the socio-cultural aspect of the built environment because it affects place attachment and the experience of place identity. The emotional dimension of architecture affects how we remember the events that take place there (Hornstein 2011), and subsequently the identity and meaning that a place acquires for us. According to Mexican-Canadian architectural historian Alberto Pérez-Gómez, emotions emerge as responses to the physical environment, at a pre-reflective level (Pérez-Gómez 2016). According to him, atmospheres attune us to the shared mood of an environment, making us feel like participants in it and in a larger whole. Atmosphere is part of a phenomenological approach to the study of spatial experience that informs the study and pedagogy of place and placemaking (Seamon 2023). Spatial atmospheres mediate our affective relation to spaces, in turn shaping the social relations and processes that take place there.

Atmosphere is multi-sensorial rather than having to do with form, style or image (Pérez-Gómez 2016). Formal and stylistic concerns dominate an ocular-centric approach to architecture (Pallasmaa 2005), a tendency that has been affected by the proliferation of visual imagery (ibid), not least in architectural education. The precedents that students consult are too often limited to photographs and renderings of buildings – often by well-known, canonical architects – that are lifted from their cultural, geographic and socio-political context, rather than engaged experiences of architectural spaces.[1] How can a more multi-sensory approach to architecture be taught?

2.0 ATELIER ZUMTHOR AT THE USI-ARC

2.1 Atelier Zumthor: a phenomenological approach based on "scientific intuition"

The Università della Svizzera italiana (USI) was founded in October 1995 and consisted of the Academy of Architecture in Mendrisio and the Faculties of Economics and Communication in Lugano (De Conti Lorentz 2021, 25). The Academy of Architecture welcomed its first cohort of 104 students the following fall (idem, 35). It offered a six-year degree, split into two cycles: a two-year cycle, the second year of which is dedicated to external internships, followed by a four-year cycle, the last year of which is dedicated to the diploma project (Mendrisio Academy Press 1997, 1998, and 1999). In the 1996/97, 1997/98, and 1999/2000 academic years, the incoming cohort was split into three sections of first-year design studios, taught by Mario Botta (director of the school), Aurelio Galfetti, and Peter Zumthor (De Conti Lorentz 2021, 35). During these three years, Zumthor had classes of 20 - 40 students, with three or four assistants (USI-ARC archive).[2] His three first-year studios were conceived as a continuous didactical structure and consisted of 19 assignments, titled A – S. Starting in the 2000/2001 academic year until 2006/2007, after which he left the school, Zumthor alternatively taught third-, fourth-, and fifth-year studios, and directed diploma projects. This second cycle of his teaching included assignments T – Z as well as other thematic studios. Alongside these studios, Zumthor taught a "Special Course" for more advanced students in the years 1996-97 and 1997-98, as well as a design studio at the Harvard GSD in the spring of 1999.

Zumthor was 53 years old when he began teaching at the Academy, and was completing the Therme Vals and the Kunsthaus Bregenz. His teaching period coincided with the development of the Kolumba Museum, the Bruder Klaus Chapel, and other projects that made increasing use of large-scale material tests and models, approaches that he was also teaching at the Academy.[3] It was shortly after he left the Academy in 2007 that he earned the Pritzker prize in 2009.

Zumthor's first-year studios taught the "foundations of composition" based on "the perception of the world through the five senses" (Mendrisio Academy Press 1997, 98). The studio intended to offer "a new, personal approach" to architectural education (ibid).

> The student[s'] abilities to perceive the world through [their] five senses was challenged in a conscious, phenomenological approach. The student[s'] biography was examined "scientifically". [Their] early experience with the "constructed" universe was recalled from [their] memory (Mendrisio Academy Press 1998, 116).

This phenomenological and personal approach to design teaching stressed the relation between "individuality" and "collectivity," and the relevance of a "personal approach" to design spaces that "serve a common need of use or beauty" (Mendrisio Academy Press 1999, 152).

The proposal document outlining Zumthor's upper-year (second cycle) studios elaborates on these concepts, describing the main didactic method as "scientific intuition":

> Knowledge and environment are an unanimous estate to profit from with dedication, but nothing without the individual intelligence: intuition, imagination, decision and action.
> *Scientific intuition* emphasizes eagerly the individual process of "acquiring" or "conquering" knowledge over the academic process of "transmitting" or "conveying" knowledge, in other words, the process of "making" knowledge over the process of getting "already made" knowledge, or even, the process of "desiring" knowledge over the knowledge itself (USI-ARC archive).

Scientific intuition, as practiced in Zumthor's studios, involves the "desiring" of knowledge based on emotionally significant memories and observations, experienced intuitively and subsequently analyzed to understand and reproduce their sensory qualities. It is a process of recognizing emotionally significant atmospheres, then dissecting and reassembling them to produce new ones.

This didactic approach reflects Zumthor's own design process, which he calls phenomenological (Zumthor and Lending 2018, 30). It works as follows:

> We look first; we feel first; and then, […] we start to analyze our feelings, not the other way around (Zumthor 2015).

This approach is based on trusting intuition and on avoiding "rationaliz[ing] and […] explaining too early in the process" (Zumthor and Lending 2018, 36-38).

2.2 The USI-ARC archives

The records of Zumthor's teaching on which this paper is based are in the USI-ARC archive. They were first studied by Lorentz in his 2021 dissertation *Teaching Architecture: Peter Zumthor and the foundations of composition,* which examines the first three years of Zumthor's teaching. Almost nothing remains of student's physical work; however, student drawings and models are documented in over 4,000 slides. There are annual teaching reports published by the school that include course descriptions and a small selection of student work. There are also binders of material relating to his teaching from 1996 until 2002. They contain assignment outlines, studio schedules, reflections by the teaching team about the success of selected exercises, student descriptions of their exercise, and internal and external faxed correspondence. According to Lorentz, documentation was interrupted in 2002 most likely because Zumthor's main assistant, the Spanish architect Miguel Kreisler, who was primarily responsible for documentation, left the atelier that same year (De Conti Lorenz 2021, 15-17). After 2002, when Ivan Beer was the main assistant, three books were published with documentation of individual studios: *Ciao Chiasso* (2005), *Make it Typical! A small atlas of architectural atmospheres* (2005), and *Bauen am Rhein* (2008).

3.0 DESIGNING ATMOSPHERES

Atmospheres affect how places are experienced, used, and acquire a sense of meaning and identity. They are experienced pre-reflectively, at the level of intuition and feeling, and depend more on sensory qualities than on form. Accordingly, Zumthor's pedagogy centers on personal intuition and on sensory experience. Following these principles, students are taught to design atmospheres as a background for social life.

3.1 Remembering atmospheres

For Zumthor, memories of atmospheres are reservoirs for designing (Zumthor 2010, 8). As he describes in the course outline for the Harvard GSD studio, designing is for him

> more re-discovering than inventing; it means to re-configure, to re-cognize, to re-assemble impressions and emotions which [he has] experienced and now consciously [tries] to recall (USI-ARC archive).

By re-assembling remembered atmospheres, he forms a mental image of the atmosphere of the future building, or what he calls an "inner image" (Zumthor 2010, 67). As Zumthor writes in the USI-ARC 1999-2000 curriculum description, to begin designing, one needs a concrete, sensuous inner image of the material qualities of the building, related to place and use (USI-ARC archive). During this process, the sensuous quality of the inner image helps him "not to get lost in arid, abstract theoretical assumptions" and "not to fall in love with the graphic quality of drawings" (Zumthor 2010, 67). He taught students to examine their remembered atmospheres, identifying physical qualities that can inform a sensuous inner image.

For Assignment A, "The personal construction module," each student chose a material that they either liked or disliked, because of a remembered personal experience (USI-ARC archive). They used that material to build a 36x18x18cm block that would convey the qualities of their memory. Students built blocks from materials such as Lego, beeswax, comic books, and match boxes. One student recalled a memory of sitting in a patted-down area in a field of tall grass, and built a grass block. Some blocks, however, were deemed not to be precise enough; for instance, a student spoke about a memory of the smell of wet asphalt, but the asphalt block that they made was already dry. Another student had a memory of how the dry plaster on house facades interacts with light, but their plaster block was too fresh and humid to show the same effect (ibid).

The first assignment of the following first-year cohort dealt with representing a remembered space. The outline for Assignment H, "A space that looks at the landscape of my youth," reads:

> Our memory is rich in images. We remember certain images. Some of them move like the images of a film. Others are still and silent. We find ourselves in a space, quietly looking at a landscape or looking inside another space. We recall exactly the space where we were, and remember exactly the view, what we saw then, as if it was a multicolored image or the scene of a movie. […] It has become an inner image that we can summon at any time (De Conti Lorentz 2021, 108).

Students had to reproduce such a personal image in a 1:20 model using primarily clay, then photograph it so that it appeared as realistic and as similar to their memory as possible. "And something of the atmosphere of the moment comes back" (ibid).

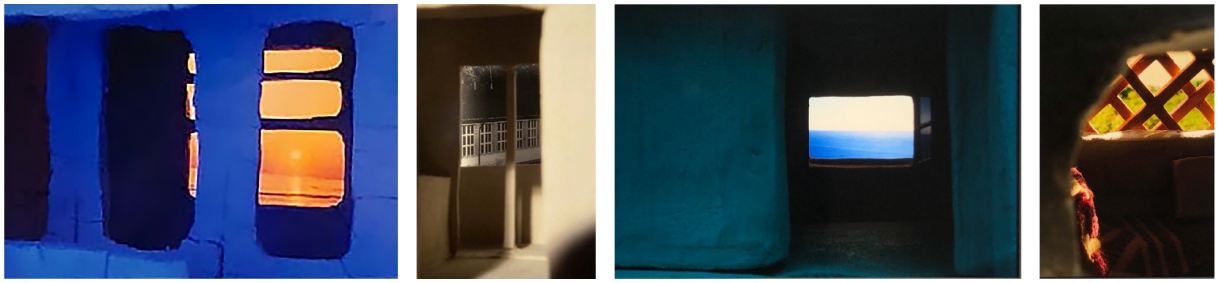


Figure 1: Assignment H "A space that looks at the landscape of my youth" (1997). From left to right: work by Gustavo Gulino, Andrea Huber, Aymone Poletti, and Mohammed Nabil. Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

Assignment K, "The typical space," pertains to memories of "typical" spaces such as a kitchen, greenhouse, veranda, or barbershop, ones that remain impressed in our memory precisely because of their non-particularity. Typicity, Zumthor writes in the assignment outline, refers to the common properties in a kitchen or a greenhouse, based on how it is used, despite individual variations. Such spaces, according to him, are "part of our collective memory" (USI-ARC archive).[4] Students documented the atmosphere of a typical space by arranging three or four materials in a 35x45x25cm box. Among the documented spaces were a U-Bahn wagon, shown with a black box, red imitation leather, a metal rod, and plastic imitation wood veneer; a movie theatre, shown with a black box containing pieces of linoleum, red velvet, and acoustic panel; an apiary as a yellow box with earth, a piece of thin copper, a pile of broken honeycombs, and beeswax (ibid). This exercise addresses the collective dimension of atmospheres. It suggests that, if students compose atmospheres based on such typical spaces, then their atmospheres might speak to a broader public.

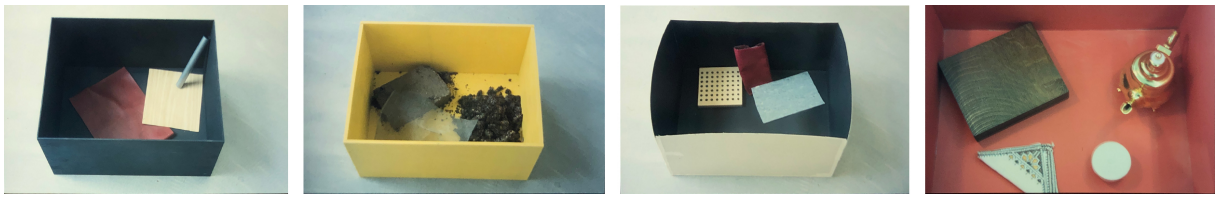


Figure 2: Assignment K "The typical space" (1998), representing, from left to right: an U-bahn wagon (Marisia Conn), an apiary (Sandra Giovanacci), a movie theatre (Maria Elena Salati), and a living room (Mohammed Nabil). Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

Assignment K also taught students to describe atmosphere through language. Their descriptions were to include only the sensory properties of the space, its use, lighting, sounds, scents, etc.; they should be "objective," not including "feelings." They need not include full sentences; "rows of words" would suffice (ibid). Such objective description, which Zumthor would also prescribe for later assignments, maintains the focus on sensory qualities and excludes anything that is not physical: ideas, feelings, concepts.

For Assignment O "A miniature," students produced an image that captures the "essential quality" of a remembered place in which the sun or rain was a determining component. It could be a collage, painting, photo, or real material, but had to be "precise and concentrated," "essential and minimal," as the assignment outline describes (USI-ARC archive). Images included a blurred roofscape seen through rain-covered glass, framed feathers, and a photo of light on the surface of water.



Figure 3: Assignment O "A miniature" (1998). From left to right: work by Chiara Del Corso, Julian von der Schulenburg, and Jela Herrling. Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

These first-year assignments teach students to identify the sensory qualities of atmospheres, to draw from their memories, and to convey this atmosphere to others through materials, model photos, collages, and language.

3.2 Observing atmospheres

When beginning a project, Zumthor says that he observes the site to form an impression of its atmosphere. He "concentrate[s] his powers of imagination" on the site, especially on its sensorial qualities and physical traces of

history (Zumthor 2010, 36-37). Observing the site in this way gives him an emotional impression that depends on feeling and intuition (Zumthor 2023). The site models built in his Atelier use materials that capture his impression of the atmosphere of a place, such as sand, coal, stone, clay, or coloured wax.

This phenomenological approach to observing the site is described in the assignment T, "Atlas," part of the 1999-2000 fourth-year studio that Zumthor taught with the London-based architects Adam Caruso and Peter St. John (USI-ARC archive). Students documented twenty buildings that had an "anonymous" appearance and that had been inhabited for many years (Mendrisio Academy Press 2001, 258) – "the normal buildings amongst which we live our lives," as phrased in the assignment outline. "Just as when a child sees a chair, table, or room for the first time," students were instructed

> to observe a building by going beyond [architectural] visual conventions and entering into a profound relationship with it, establishing a significant emotional rapport with [their] own work. Thus, architecture can be considered a way of looking at the world with renewed intensity (Mendrisio Academy Press 2001, 258).

"Really seeing" one's surroundings requires, according to the outline, questioning conventional representations such as plans, sections, and perspectives, which "tend to exaggerate the importance of formal composition" (USI-ARC archive). Instead, students should use means of representation that can "expose the violence of a new window opening inserted into a heavy brick wall," or that can show the traces of inhabitation in a small house. They should record the buildings through photographs, full-scale drawings, and written descriptions, "emphasizing what is observable and real" (ibid).

For the 2000-2001 fifth-year assignment W "Portrait of Pavia," Zumthor instructed students in the assignment outline to observe a village in the Italian province of Pavia "with a childlike gaze, free from perceptual prejudices" (USI-ARC archive). They should focus on sensory qualities:

> [L]ines, patterns, surfaces, textures and masses; weight, temperature, sound, movement and light are patiently observed as if for the first time. The approach is driven by emotional confidence (ibid).

Students were asked to observe four aspects of their assigned village:

> the phenomenology of water; motorways, railways and paths; the vegetation, fabric and masses; the solid bodies of built or tellurian objects (ibid).

Based on their observations, documented through photographs, diagrams and written descriptions, students made wooden models of their assigned sites (ibid). They should bring out the qualities they observed; for instance, the group investigating Cascina Crocedue built the ground out of horizontally stacked layers of wood to evoke the linear patterns left by tractors on the farmland (ibid).



Figure 4: Assignment W "Portrait of Pavia" (2000). Photos and model of Cascina Crocedue (students unknown). Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

Zumthor proposed a similar approach to site study for the 2003-2004 fourth-year studio "Solutions for the double periphery," this time more explicitly prompting students to consider their emotional response to the site. He calls this approach "energy modelling" or "emotional relief" (Mendrisio Academy Press 2005, 189).

> We seek the things that move us; the emotional face of the territory, identity, intensity, special atmospheres that allow themselves to be perceived and defined physically, which can be experienced in the place. We understand the body of this development […] as an organism clinging to the terrain, a cellular tissue that lives, changes, dies and is renewed continually. We want to learn to understand and render visible the structure, the construction, the character of this body (ibid).

This "emotional relief" was applied to the study of Chiasso, an urban area on the "double periphery" of Milan and the Swiss border, which is said to be a merely functional urban agglomeration, lacking character and identity. It is a "typical" border condition town (idem, 188). Zumthor prompted the students to observe the life of the site: where the crowded places are, the pedestrian passages, abandoned places, night life, and where immigrants spend their time; the physical, sensorial aspects: where water can be heard, where there are enclosures, and where the scars in the ground are; and what *moves* the students: where they feel small, their favourite roofs, the unique beauties of Chiasso, what they find surprising (Zumthor 2005, 10). These questions help students to *empathize* with Chiasso and to form an emotionally significant impression of it, based on which they built models of the site using materials that emphasized this impression, such as clay, metal plates, and wire.

Observing and empathizing with the life of a place also requires spending time there. The first-year assignment F, "In situ," the first assignment of the second semester, began with the entire class observing the sunrise from the nearby Monte Generoso. In the first portion of the assignment, "F1: First encounter," students were divided into small groups and assigned a site in or near Mendrisio. The outline instructs them first individually and personally to "encounter" the place, only subsequently exchanging observations with the group. For "F2: The time of place," students chose one viewpoint from which to photograph their site. They made one photo and one 10-second sound

recording every hour, for 24 hours. Then, based on their observations, for “F3: Remodelling the site,” each group built a physical model that would capture the essential elements of their experience of that place. Only as a last step, in “F4: Analysis of the place,” students produced scaled orthographic drawings and diagrams of their sites.

These assignments teach a way of looking anew at the landscape and built environment, at its textures, material qualities, and at aspects that are not easily represented in scaled orthographic drawings. They teach students to empathize with the site, with its life, forming a personal emotionally significant impression of it. This impression is captured and conveyed to others through models, notes, sketches, and photographs.

3.3 Imagining and building atmospheres

In Zumthor’s teaching, the design of an intervention grows out of a personal engagement with the site, as described above, and is conceived as a setting for – or a spatial mood for – the life that takes place there.

For example, assignment F “In situ” was followed by assignment G, “1:1 intervention.” The aim of the project was to render visible the particularity of the place – its topography, function, form, history, meaning – through means such as water, light, materials, and sounds. Each group produced a setting for a social event, for instance: covering an area of the Vecchio Borgo (old town) with four cubic meters of black gravel and installing four large white umbrellas for a tasting of self-made gazpacho; a sound installation in the nearby Chiesa Rossa that would give a voice to the old church, with crates of cherries around the site; an installation of incandescent lights, candles, cups, and a selection of wines at the canteen on campus; projecting four 4000 watt theatrical lights at the former Saceba cement factory and seated audience at 10:40pm, then turning them off to experience the darkness. The interventions were atmospheres for events.



Figure 5: Assignment G “1:1 intervention” (1997) in the Vecchio Borgo, Mendrisio (students: Sabine Andrey, Silvia Carnelli, Rada Fornara, Annette Göhringer, Laura Perolini, and Elena Saricu). Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

Applying this approach to the design of buildings, Zumthor taught a spring 1999 studio at the Harvard Graduate School of Design in which students composed a sequence of atmospheres for a house without designing its overall geometry; the studio was titled “The House Without a Form.”

> This design exercise stops at the delicate line just before form begins to emerge out of the process of sensual composition. If the composition works, it will be easy to imagine the resulting architectural forms – in fact, they will almost be there already (USI-ARC archive).

Rather than drawing plans and sections of the house, students made 1:1 collage-like installations or projections showing the physical, sensuous qualities of a sequence of seven rooms, accompanied by “strictly descriptive words” of physical qualities (ibid). Students chose sites with which they already had a personal connection and showed moments of how they might be experienced, for instance a living room window that looks onto the Mississippi river, or a house that opens onto a hilly landscape of red earth in Cyprus, so that one could feel the earth.

Reflecting on this studio later that year in the document “Curriculum 1999-2000”, Zumthor remarked that, while the Harvard GSD students had previously designed large architectural projects, presenting them in scaled orthographic drawings and models, they only had a vague idea of how their building would feel and how it would be physically assembled (USI-ARC archive). Supposedly, he writes, there is insufficient time in school to consider these aspects, and students expect that they will learn them in practice.

> But I wonder: Is that true? Aren’t the images of a building’s specific physical presence, the images of material construction, the atmosphere of the rooms […] part and parcel of the basic concept of any design? Doesn’t an awareness of these things belong to the beginning and not the end of the design process (ibid)?

He continued this approach the following semester at USI-ARC, for the fourth-year assignment U: “Hotel.” Students first described atmospheres through photographs, collages, and written descriptions, but this time took the design process further, making materially evocative conceptual models and then drawing floorplans of the hotel. Students’ initial descriptions were of the façade and interior materials, lighting, furnishing, and sounds. For the last part of the assignment, students made 1:20 models of one room in their hotel and photographed it, so that the photo would appear realistic. These models resemble ones that Zumthor’s Atelier builds, populating them with furniture, fixtures, objects, vegetation, and cut-out photos of people. Showing how spaces are occupied helps him to imagine the life that might take place there (Brand 2017, 228).



Figure 6: Assignment U “Hotel” (1999), 1:20 interior model photos by (left to right) Catherine Dietschi, Filippo Colombo, and Luca Bazzi. Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

Imagining and representing buildings as a setting for life is also how Zumthor taught the design of a single architectural element in the first-year assignment I: “A window for my friends, to read by the light of the lake” (USI-ARC archive). Using no more than three materials, each student built a 1:1 fragment of a window and photographed it by the nearby lake in Riva San Vitale. The photos were to show only the window fragment, the water and the sky, and an open book or part of it. Students only had to build the portion of the window that would appear in the photograph. The photos were printed in black and white, at 60 x 90 cm, attached to a hard support, and were considered successful if they provoked a longing to read by that window.



Figure 7: Assignment I “A window for my friends, to read by the light of the lake” (1997). From left to right: work by Marta Monti, Beatrice Morelli, Andrea Huber, and Federica Ballerini. Source: USI-ARC archive. By kind permission of USI-ARC. All rights reserved.

These assignments show that atmospheres are settings for the life that takes place there. Zumthor guides students in this direction by formulating an intention for these atmospheres, describing them in terms of specific materials and multi-sensory experience, before designing the form.

CONCLUSION

Zumthor taught his students to have an awareness and appreciation for the sensory qualities of the environment and the emotional impact of materials, as well as how to form an intention for these qualities at the beginning of the process. His teaching reflects his own phenomenological design approach based on remembering emotionally significant atmospheres, forming an impression of the site, representing it through evocative models, and forming a strong sensuous inner image of the atmosphere of the future building to guide the design process. His teaching approach suggests the following lessons for the future of architectural pedagogy:

First: working with the sensory qualities of ‘real’ materials. Students can develop an attention to the sensory qualities of materials and spaces by working with ‘real’ construction materials, and through assignments that address sensory qualities: sight (especially the interaction between materials and light), sound, touch, and smell. Such assignments also teach students to take notice of, and to become sensitive to, these qualities in the built environment, so that they can later make use of them in their designs.

Second: starting from personal memory, experience, and feeling. Students can learn to use their personal felt experience to discover the material qualities that influence atmosphere, such as sight, sound, smell, and textures, which can inform their designs for new atmospheres. Drawing from personal memory can valorize everyday environments and the diversity of student experiences. Moreover, atmospheres are experienced above all emotionally, intuitively, and pre-reflectively. Students can be helped in designing atmospheres if they recognize their felt experience, trust it, and then seek to understand it. Personal feeling and experience can be a starting point for critical thinking. This approach is also student-centered, encouraging them to discover knowledge through experience rather than taking in already-made knowledge, as Zumthor describes with the term “scientific intuition.” This approach also allows students to become aware of collectively lived atmospheres.

Third: imagining the atmosphere at the beginning of the design process. When students begin designing by describing the sensory experience of their building, through visual means as well as through language, then this imagined atmosphere can guide the development of the form. Representing and describing the intended

atmosphere can be part of a collaborative process, as it is in Zumthor's practice, where the inner image develops in dialogue with collaborators and clients.

Fourth: designing atmosphere as a background for social life. The design of atmospheres can be an integral part of the event through which people experience a space, and can contribute to the social dimension of environments. The designing and building of sensorially rich atmospheres can attune people to their environment and give emotional significance to the life and activities that unfold there.

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ENDNOTES

[1] "This remark about precedents is based on the book *(Un)Common Precedents in Architectural Design* that the author co-edited with Federica Goffi and Kristin Washco (Goffi, Potworowski, and Washco 2025).

[2] The documents at the USI-ARC are not part of an indexed archive; they are stored in binders and unlabelled boxes. Documents from the archives, including images of student work and assignment outlines, are therefore named in the text and referenced as "USI-ARC archive." The copyrights of the documents and student work are owned by the school, Academy of Architecture – Università della Svizzera italiana (USI-ARC).

[3] For a further explanation of the correspondences between Zumthor's practice and teaching, especially in relation to representation practices, see De Conti Lorentz (2021, 250-255).

[4] This and subsequent citations from assignment outlines A to O are translated by the author from the original Italian. See also the translations of Zumthor's first-year assignments in De Conti Lorentz (2021, 90-133).

INNOVATIVE MATERIALS AND CONSTRUCTION

Pedagogical Approach for Additive Manufacturing of Molds to Produce Topological Interlocking Assemblies

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ABSTRACT: With bespoke fabrication on one end and mass production on the other end of the fabrication spectrum, this paper focuses on custom repetitive manufacturing. It reviews the process and outcomes of a studio offered at Illinois School of Architecture. The objective of the studio was to enable students to design building components for assembly, followed by digital fabrication of the components. The pedagogical methodology employed a project-based learning (PBL) method in the first project, and a problem and project-based learning (PPBL) method for the second project. In the first project, students developed an understanding of precast elements as well as acquiring a set of skills in additive manufacturing (AM) and mold making by analyzing a built precast case study. In the second project, students were tasked with designing topological interlocking assemblies (TIA) while designing a reusable mold for casting the modules. Pedagogy encourages reflecting on past architectural projects by exploring the rationale and limitations of traditional production techniques, before rethinking design and production methods by using advanced building technologies. This manuscript explains the process and outcome of the second project. Among the challenges to be solved in the second project was 1- designing a block geometry with complex curvatures on all sides for mortarless assembly; 2- designing the assembly resulting from the design of the block and iterating while assessing the daylighting and structural performance of the assembly; 3- digital design and fabrication of a plastic mold for repeatable casting of the block geometry. The projects were assessed based on responding to these three challenges. The studio resulted in installations that were exhibited at the end-of semester showcasing students' projects. The installations demonstrated a proof-of-concept for 3D printing plastics as a formwork for repeated casting of interlocking concrete blocks.

KEYWORDS: Pedagogy, Additive Manufacturing, Topological Interlocking Assemblies, 3D printed molds, precast.

INTRODUCTION

This manuscript explains the pedagogy of a studio offered at Illinois School of Architecture. The studio is at the intersection of understanding additive manufacturing (AM) technology, designing topological interlocking assemblies (TIA), and AM of plastic molds. Therefore, the paper is structured around three pillars: 1- employing problem and project-based learning (PPBL) method for teaching AM in a studio setting; 2- designing TIA; and 3- using AM for fabricating plastic formwork as an emerging construction method for precast. The background on each pillar is explained in section 1.0. Next, section 2.0 discusses the pedagogy methodologically. Afterward, section 3.0 reviews the students' projects and briefly explains the design and fabrication approach. Section 4.0 discusses the development of students' skills in relation to the three pillars of pedagogy throughout the semester, and the criteria for assessing the projects, before the Conclusion section.

1.0 BACKGROUND

1.1. Employing a PPBL approach for teaching AM

According to Celani (2012), digital fabrication laboratories have a potential of promoting experimental methods in architecture together with a scientific approach, which is the basis of contemporary architecture practice (Celani 2012). Focusing on pedagogical approaches around experimental learning, problem-based learning (PBL) and learning by doing (LBD) are two teaching methods based on knowledge gained in the experiential process of learning. PBL enables students to improve their learning styles by offering similar experiences to real-life professional practice. LBD on the other hand focuses on active learning style (Özman and Selçuk 2023). Ilkovič expands on PBL method by presenting "problem and project-based learning (PPBL)" method. In PPBL, the teacher sets a problem in an assignment which is solved in a project development way (Ilkovič, Ilkovičová, and Špaček 2014). Project-based learning is adopted in many courses across US universities where students collaborate in groups to develop 3D printing skills while working on creative and demanding projects. Examples include the course implemented in MIT's 'additive manufacturing' course (Go and Hart 2016), a course offered at University of Texas at Austin and Virginia Tech (Williams, Tech, and Seepersad 2012), and finally Missouri University of Science and Technology's course on 'Rapid Product Design and Optimization' course (Liou, Leu, and Landers 2012). From a different perspective, researchers have focused on studying different contexts in which 'university students are taught about 3D printing'. These categories include teaching students about either the '3D printing technology itself,' or about '3D printing through project-based learning' (Ford and Minshall 2019). Celani (2012) explains that in some schools the initial impact of digital fabrication laboratories in architectural education was simply the increase in the number of physical models produced. However, it is important that students learn to use the machines and

understand the concept behind each different digital fabrication strategy in specific courses. This will allow students to become closer to the production process and to have better control over building parts and materials (Celani 2012).

1.2. Design of TIA

The knowledge embedded in centuries-old techniques offers unique opportunities in the context of digital design and fabrication. Stereotomy, a traditional construction technique, allows architectural structures to be built from discrete stone elements. In this sense, stereotomy is understood as the shaping of solid structural materials to form unique parts that integrally comprise an assembled whole. Stereotomy is seen in design and construction of topologically interlocking assemblies (TIAs) such as Abeille and Truchet flat vaults (Brocato and Mondardini 2012). TIAs comprise solid elements, and their overall structural integrity relies on each element being kinematically constrained by its neighbors. Such systems establish equilibrium through compression forces, with the weight of each heavy block used against itself. Given fixed boundary conditions, the assemblies can resist forces without any additional binding material such as mortar—adjacency replaces mortar. In addition, the global geometry of the assembly can be controlled to minimize deflections and increase the efficiency of the system.

Giuseppe Fallacara and Maurizio Barberio have put forward the term *digital stereotomy,* characterized as the "union between stereotomy and three-dimensional computer modeling techniques in relation to topological transformations and deformations" (Fallacara 2009). Architects and designers have studied the design and assembly of TIA using digital design, computational simulation, and digital fabrication techniques. Many previous studies have focused on parametric design of TIAs to create differentiation either in terms of modules' porosities (Tessmann 2012). Some have focused on structural performance assessment of the assemblies through simulation (Schaare, Riehemann, and Estrin 2009), while others have emphasized prototyping the assemblies using digital fabrication techniques (Brocato and Mondardini 2015). While the term digital stereotomy aims to characterize the capabilities of computer modeling and subtractive CNC techniques, researchers propose 'Additive Digital Stereotomy' (ADS) to describe the way that formwork can be 3D printed for casting topological interlocking modules (Emami and Holmquist 2020). They argue that in calculating and fabricating discrete, structurally interdependent units, ADS is an innovative and true form of stereotomy. ADS is furthermore a potentially more effective method of stereotomic fabrication since it allows for optimizing the weight of modules by geometric design, using low density concrete for casting, as well as reusing formwork for multiple castings.

1.3 AM of formwork for precast concrete

Concrete has excellent structural properties and can be shaped into many complex shapes. However, the required materials and skill sets for molding concrete add to its construction cost, and ultimately CO_2 emissions of this construction method. AM is an evolving construction process that is revolutionizing concrete construction. For creating 2.5 dimensional geometries, the formwork can be eliminated altogether, allowing direct digital fabrication of concrete also called 3D concrete printing (3DCP). For creating complex 3-dimensional geometries with intrinsic surface pattern, 3D printing mold is the leading method. This approach is an indirect digital fabrication of concrete referred to as 3D printed formworks (3DPF). Advances in recycling and material science hold promises for future plastics made from renewable sources and reused numerous times during their lifecycle. Considering the reusability of the formwork during digital fabrication phase followed by plastic recycling could take us one step closer to a circular economy. Many research studies have used bespoke 3DPF where the formwork has been destroyed with a heat gun (Jipa et al. 2019), stayed in place (Aghaei-Meibodi et al. 2018), or dissolved (Sitnikov 2019) .However, the 3DPF needs to be used multiple times to be compatible with the economics of scale. Therefore, custom repetitive manufacturing, where unique elements are designed and fabricated for a specific project is the focus of this paper. There are a few recent research studies that have focused on repeatability in design and reusability of the 3DPF. Examples include the Min-Max panels (Aghaei-Meibodi, Odaglia, and Dillenburger 2021); the topologically interlocked blocks of a stereotomic arch that were repeatedly cast into 3D printed elastic molds (Emami 2021); the topologically optimized beam realized through the reusable casting of a 3D printed TPU formwork (Xu et al. 2022); and the façade panels cast in reusable TPU formwork (Emami 2023).

2.0 PEDAGOGY

2.1. Project description

The project description provided to the students tasked them with designing and prototyping a sunscreen made of topological interlocking blocks. Both sides of the screen were required to be exposed and to be designed in a way that allows having a view from one side to the other. Students needed to make decisions on the perforation ratio and material distribution of the modules and consider achieving the highest strength with the least material use. The screen was required to be a self-standing structure that is not attached to a sub-structure for support. Thus, each row needed to support the weight of the blocks above it up to 3 meters (~10 feet). The method of fabrication was constrained to using 3D-printed formworks for the repeatable casting of the modules. Students were offered two materials for AM. Polylactic Acid (PLA) and Polyvinyl alcohol (PVA) which is a water-soluble filament. Finally, students were asked to create an installation by using at least ten modules that show a portion of the wall.

A total of ten students were enrolled in the studio: six first-year graduate students and four second-year graduate students. At the beginning of the semester, students' *familiarity*, *comfort*, and *proficiency* with computational design and digital fabrication tools was assessed. *Familiarity* was defined as having encountered the tool before by having opened it at least once. *Comfortability* was defined as being able to use the tool to some extent. *Proficiency* was defined as having the ability to effectively use the tool. Rhino NURBS modeling platform (Robert McNeel & Associates 2018) was recommended as the preferred computational aided design (CAD) platform to be used by the students. Regarding computational aided manufacturing (CAM) skills, AM was the key skill that was surveyed.

The students' skillset in CAD and CAM prior to the start of the studio is summarized in Table 1. Synthesizing the information presented in Table 1, all students expressed having some level of familiarity with Rhino. 40% of the students stated that they are comfortable with it, while 30% of them indicated that they are proficient in using it. Regarding digital fabrication techniques, all students expressed that this studio is the first digital fabrication studio that they are taking. Students' knowledge in using 3D printing was explicitly assessed. All students expressed familiarity with the concept of 3D printing. However, they had never used it in any of their school projects, and they expressed that they had never directly operated a 3D printer. This assessment reinforced the instructor's approach in structuring the pedagogy around teaching the students about AM technology first and foremost. It was anticipated that the students' CAD skills would improve during the Design of TIA. Next section further expands on the three pillars of pedagogy.

Table 1: Students' level of *proficiency, comfort, or familiarity* on a scale of 0 to 3 regarding CAD and CAM techniques. Source: (Author 2024)

	Student 01	*Student 02*	*Student 03*	*Student 04*	*Student 05*	*Student 06*	*Student 07*	*Student 08*	*Student 09*	*Student 10*
CAD skills: Rhino	3	2	1	1	2	1	3	2	3	2
CAM skills: AM	1	1	1	1	1	1	1	1	1	1

0 Not familiar at all; 1 Familiar; 2 Comfortable; 3 Proficient.

2.2. Three pillars of Pedagogy

The pedagogy is organized regarding the three pillars that were explained in the background. First, the studio is an example of *employing a PPBL approach for teaching AM* in a studio where students collaborated in teams of two or three. During the first few weeks of the studio, students were taught about AM through a series of workshops. This included learning about employing AM for creating physical models, in addition to the 3Dprinting technology itself. The workshops covered some details about the hardware, the mechanics of the machines, and safety to enable them to operate the machines. This was an implementation of learning by doing (LBD) approach in teaching AM. It should be noted that project-1 was specifically designed to allow skill development, and the grading was forgiving. Therefore, the learning curve did not put unnecessary stress on students. Rather, it demonstrated the importance of paying attention to the process of running a 3D printer machine.

Second, the studio is an example of teaching *Design of TIA* using a NURBS modeling platform. Students were presented with examples of historical cases of mortarless TIA vaults made of stone. Each group was then asked to design four to six TIA concepts depending on the number of students per group. For example, a group made of two students versus three students was asked to present a total of four and six TIA concepts respectively. The students were also asked to 3D print four modules of their designed TIA to demonstrate their interlocking mechanism. This approach helped the teams to start with a good number of concepts that were later combined or allowed the students to pick one among many. Also, the physical models allowed them to develop the interlocking mechanism through feedback, in-class conversations, and iterations.

Third, the studio is an example of teaching about *AM of formwork for precast* as an emerging construction method. First, the students were introduced to rubber mold making in the first project to familiarize them with the sequence of mold design and mold making. It is important to note that the topic of AM of molds is closely aligned with the instructor's research area. Therefore, there were many built models and cast instances of the mentioned construction method in the Digital Technologies in Architecture (DiTA) research lab that were presented to the students to help them understand the idea. Students had a good platform to start designing the mold for their TIA, followed by digitally fabricating them.

Since educating each pillar required a timeframe, the curriculum was designed in a way that the students are first provided with a window of opportunity to learn about each topic. The first quarter of semester focused on teaching and learning about AM. During the second quarter of the semester, the students were provided with the project-2 description and were introduced to the concept of TIA. During the third quarter of the semester, students focused on the design and fabrication of formwork for their designed blocks. The timeline for teaching each topic and the overlaps between the three topics are demonstrated in Figure 1.

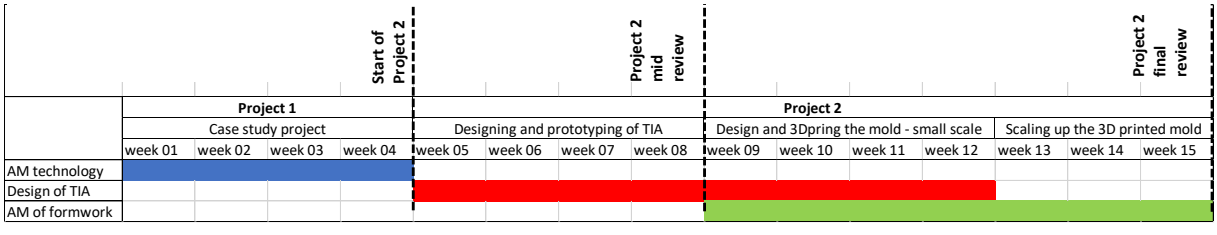


Figure 1. Timeline for introducing the three components of the studio and the time allowed for developing students' skillset in each topic. Source: (Author 2024)

3.0 REVIEWING THE PROJECTS COMPLETED IN THE STUDIO

The studio resulted in a total of four projects that were showcased as installations at the end of the semester. Three out of four projects which are shown in Figure 2 are reviewed and discussed in this manuscript. The following subsections are focusing on each project.

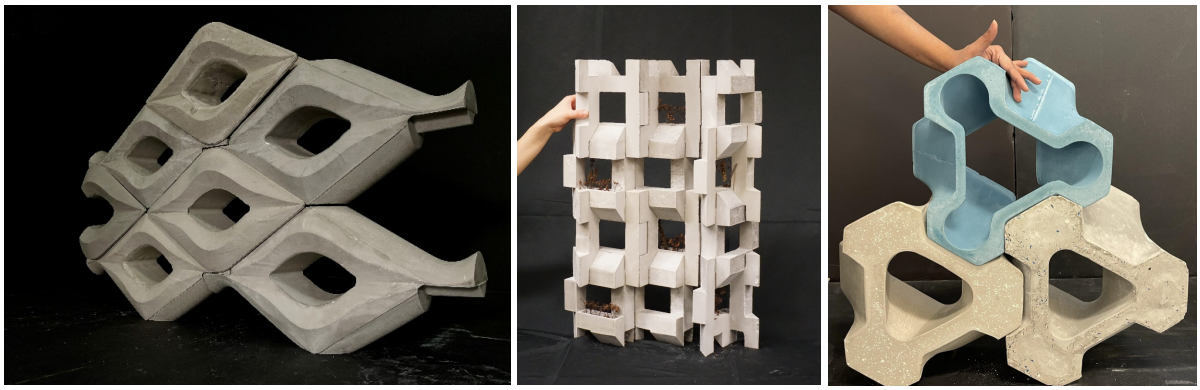


Figure 2. TIA assembly of the three projects: The Wave (left); Polyomino (middle); Re-Block (right). Source: (Author 2024)

3.1. The Wave

A team made up of three students designed, iterated, and prototyped “The Wave” project. All of the team members were first-year Graduate students with an undergraduate degree in Architecture. The Wave aimed to achieve a seamless and organic geometry that acts as a decorative perforated courtyard wall resonating with the landscape. The proposed sunscreen was designed as a courtyard wall, an internal partition wall, or a sculptural element. This was inspired by the study that courtyards with perforated walls are extensively used in hot and humid climates such as India and Sri Lanka. The interlocking system that the team designed for their systems consisted of designing a concave/convex surface on the edge of the module which would restrict the movement of the modules in the z-direction. They then designed connecting parts of the module that constrained the movement in the x and y-direction. A total of two module types were designed. Module A, the module with two tails at each end forming the first row of the assembly, measured 14” wide and 6.81” tall with a thickness of 2.41” (Figure 3-left). Module B, the module forming the second row of the assembly, measured 11.53” wide and 6.81” high with a thickness of 2.8” (Figure 3-middle). The team iterated at three different scales, and scaled up as they resolved design and fabrication issues. Their first model was 2”-wide, increasing to a 7”-wide model, and the final prototype was a 14”-wide model.

Regarding mold design, the team designed a six-part mold that comprised of a plug, a base with an elliptical bump that would hold the plug, and four walls (Figure 3-right). All parts were printed out of PLA and were reusable. The full-scale 3D printing of the mold was challenging. This was because the bed size of the 3D printer (Raise 3D Pro3 plus with a bed size of 620, 626, 1105 mm or 24.4” x 24.6” x 43.5”) was smaller than the size of the mold’s base. To overcome this challenge, the base of the mold was divided into three pieces and was placed vertically on the print bed. Ultimately, only the central part of the base which had undulations was 3D printed. The other two parts, which were flat pieces, and were designed for clamping the walls and the base to each other were made from wood. Due to the heat generated during the casting process, the plug deformed after using it two to three times as it had less infill density. To avoid this happening in the future, the core should be printed with higher density so that it is more durable. The TIA assembly demonstrated excellent stability when installed during final review.

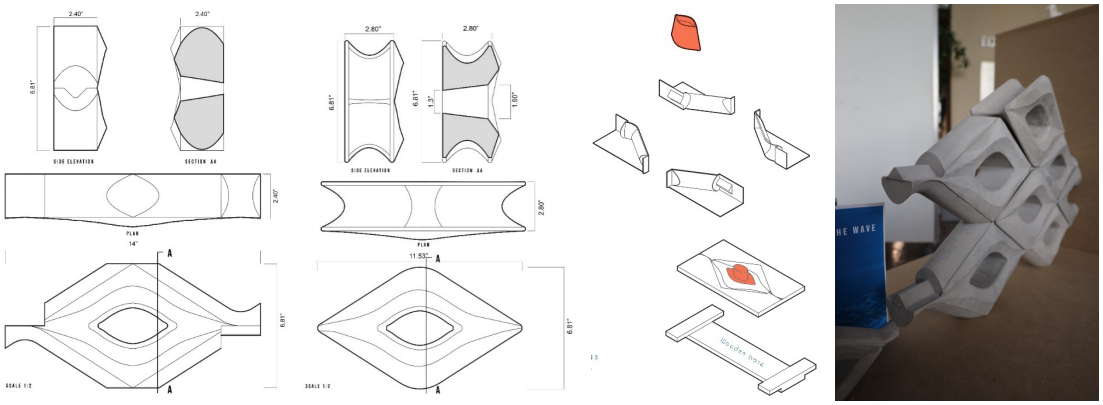


Figure 3. Project Wave: Module-A drawing (left); module-B drawing (middle); A six-part mold was designed (left). Design and drawings by Bryant Nunez, Harshini Varanasi, and Samruddhi Shirdhankar. Source: (Author 2024)

3.2. Polyomino

A team made up of three students designed, iterated, and prototyped “Polyomino” project. All the team members were Graduate students with an undergraduate degree in Architecture. One of them was a second-year graduate

student whereas the other two members were first year graduate students. Polyomino is a demonstration of micro-design impact on macro scale. This project seeks to innovate construction methods in the precast concrete industry by designing one module that could be assembled in three different ways to each other: two ways horizontally and one way vertically (Figure 4-left). This allowed flexibility in assembly and the possibility of achieving numerous ways that the system could grow in different sites and conditions by just using a single module. The complex design of the module went through many iterations at the small scale before a final mold design was achieved. The final mold iteration consisted of 11 reusable mold parts and one central core that had to be melted. The final mold design and multiple cast pieces assembled into each other is shown in (Figure 4-right). The TIA assembly demonstrated excellent stability when installed during final review.

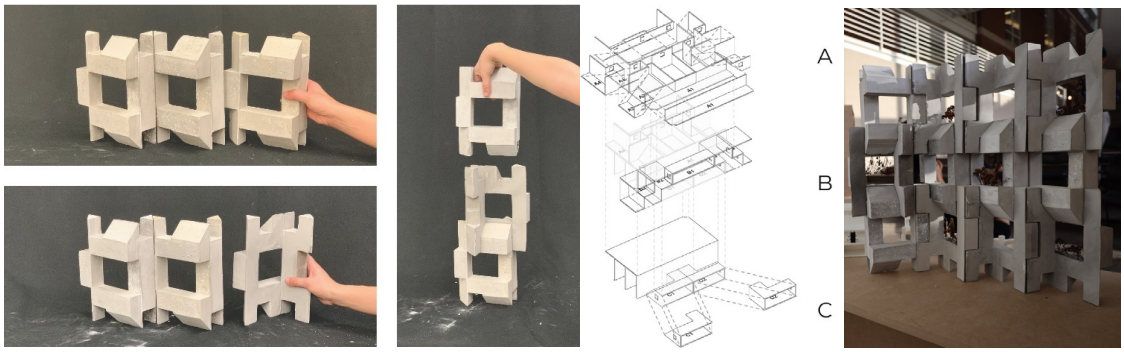


Figure 4. Project Polyomino. One module was designed to assemble in three different ways to other modules horizontally and vertically (left); final mold design (right). Design and drawings by Amir Zarei, Atousa Esmaeili, and Franchelle D'Souza. Source: (Author 2024)

3.3. Re-Block

A team made up of two students designed, iterated, and prototyped "Re-Block". Both team members were second-year Graduate students with an undergraduate degree in Architecture. Re-block typological element was designed to investigate the characteristics of the geometry to reflect those in the construction. The module was designed to integrate aesthetics, functional technology innovation and production efficiency. It investigated the potential of digital fabrication in traditional concrete construction. With the design of this module, the students aimed to replace traditional ornamental brick which needs expertise for construction with a more efficient module. This team approached geometry design by following the Albeit vault modules. The team investigated an array of geometries that were interlocking with each other using single curvature and double-curvature surfaces (Figure 5- left). Ultimately, a geometry with double curvature surfaces was selected. The geometry demonstrated excellent stability once it was assembled with the neighboring modules (Figure 5- middle). They tested various mold making methods and varying scales of interpretation to understand the way that concrete behaves in different portions of the geometry. With each iteration of the mold experiment, gradual scaling up helped them better understand the overall strength of the geometry and its interlocking accuracy. The mold design iterations were done at a 1:4 scale. The final mold design comprises three reusable outer PLA shells that were retracing the exterior geometry (Figure 5- right). The internal mold wall was a single piece of PLA that would have been destroyed before each demolding cycle using a heat gun. The TIA assembly demonstrated excellent stability when installed during final review.

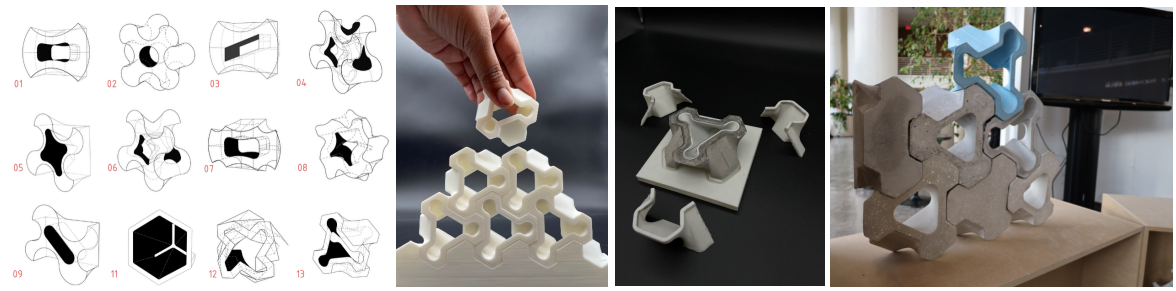


Figure 5. Project Re-Block. A series of topological interlocking geometries were explored (left); the selected interlocking geometry was 3D printed in PLA (middle); Final mold design (left). Design and drawings by Avinash Verma and Krishna Jayachandran. Source: (Author 2024)

4.0 DISCUSSION

4.1. Timeline of students' skill development regarding the three pillars of pedagogy

Students' skill development regarding the three pillars of pedagogy, namely *learning about AM technology*, *Design of TIA*, and *AM of formwork for precast* that were explained in section 2.2 are qualitatively demonstrated in Figure 6. Looking at the figure, the x-axis is the number of weeks into the semester. The y-axis shows a scale ranging from one to five. One is an abstract starting point that presents *Poor Ability*, whereas five represents *Excellent Ability*. It should be noted that five does not refer to absolute professionalism in any certain area. Rather, it demonstrates the maximum potential that a student could reach during a 15-week semester and/or reaching a point where no further improvement was planned for a certain skill. Also, it should be noted that these are an average trend for the whole studio based on the observation of the instructor and do not consider the performance of the outlier students who

were quicker or slower in grasping a concept compared to the average. The definition of the scale ranging from Excellent to Poor is organized based on *Outcome* and *Learning Trajectory*, summarized in Table 2.

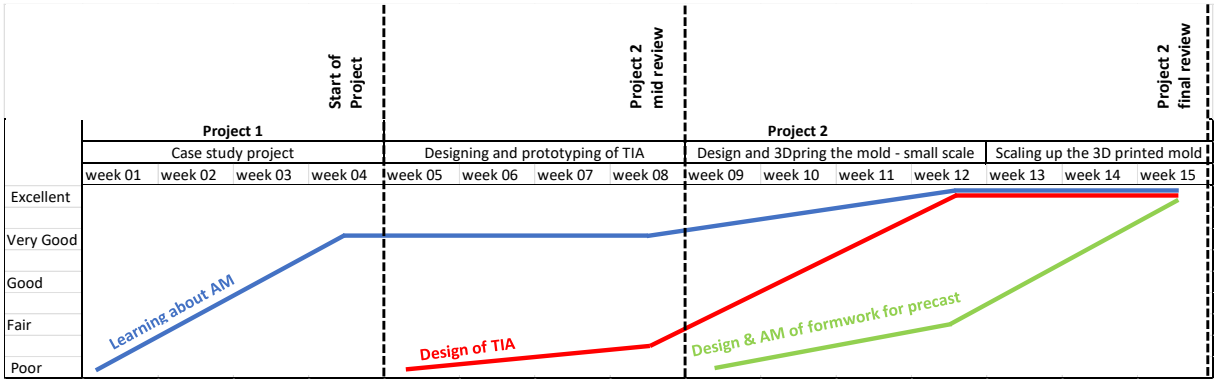


Figure 6. Students' skill development timeline in three pillars (AM technology, Design of TIA, Design and Am of formwork) in a 15-week studio project. Source: (Author 2024)

Table 2: Definition of the rating scale regarding students' skill development throughout the semester. Source: (Author 2024)

Performing ability	*Outcome*	*Learning trajectory*
Excellent	*Outcome is consistently produced and is optimized through detailed control of the process.*	*Students appear confident in the topic and demonstrate an excellent grasp of the topic.*
Very good	*Outcome is consistently produced.*	*Students appear confident in the topic.*
Good	*Outcome is consistently produced.*	*Students have had many failure/success cycles and are at a stage that obtaining an outcome can be predicted.*
Fair	*Some random outcome is produced.*	*Students are still learning about the topic through failures.*
Poor	*No tangible outcome is produced.*	Students are at the beginning of the learning process.

Looking at Figure 6, students' skill development in *learning about AM technology* was significant in the first quarter of the semester. Putting students in charge of operating their designated 3Dprinters presented challenges and opportunities. One of the main challenges was that students were not accustomed to paying attention to how a machine works. Therefore, the first couple of prints sent by many students failed since they did not follow the detailed instructions. The delay caused by failed prints negatively affected students' progress. After that learning curve, students' attention to how the machine works increased significantly, and their success rate in operating the machine increased. Students' skill reached a *Very good* level by week 04 that allowed them to utilize the AM technology effectively during working on project 2. The development of this skill stopped in the second quarter of the semester, as students focused on understanding the project requirements and developing their design concepts. However, it started to improve again in the third quarter of the semester when students needed to print thin-shelled plastic molds. They developed an in-depth perspective about the limitations of the material and the machine upon printing thin-shelled plastic. They learned about extruding filaments other than PLA, such as PVA, and its required printing settings. Also, as they were using the machines more frequently, and the size of their artefacts was increasing, they paid more attention to optimizing the print time. They optimized print time by controlling the orientation of the object on the print bed, reducing the infill percentage, and printing in 'draft resolution' versus' high resolution' by changing the printing speed.

Looking at the Figure 6 regarding students' skill development in *Design of TIA*, it started in week 05, and the slope of development was gentle during the second quarter of the semester. By the end of the second quarter, it had barely reached a *Fair* level. It was challenging for students to grasp the concept of topological interlocking blocks for creating mortarless assemblies. Many of the first design iterations created by them were employing typical methods of assembly such as stacking or weaving. The initial blocks that the students designed went through many iterations through having in-class conversations to demonstrate how the perimeter surface curvatures can be altered to constraint its movement in x, y, and z-axis. Furthermore, not all students were proficient in using a NURBS modeling platform for designing and manipulating curved geometries at the detail level. Therefore, there was a learning curve for many of them (70% of the students) to develop an in-depth knowledge of the NURBS CAD platform before their skill reaches a level that serves their project. There was a sharp increase in students' understanding of TIA after mid review and during the third quarter of the semester. This shows that students simply required more time to grasp the idea and test their prototypes for making TIA. Also, they started to incorporate other aspects of the project description, such as view requirements, optimizing the thickness of the blocks affecting weight, etc., during this time. The Design of TIA was nearly unchanged during the last quarter of the semester.

Finally, Figure 6 represents students' skill development in *design and AM of formwork for precast.* This phase started after mid review and at the beginning of the third quarter of the semester. Design and AM of molds coincided with the sharp development in Design of TIA, thus it started with a gentle slope. However, it was the key focus of the project during the fourth and last quarter of the semester. Many design and fabrication iterations of the formworks were conducted during this phase. Since the printing time was becoming more significant with increasing the size of the components, students were developing other aspects of their studio project in parallel to this activity, such as creating diagrams and drawings, and improving their project presentation.

Looking at the overall trend and overlaps of three plots, the second quarter of the semester seems to have the least amount of development in the three areas cumulatively. The second quarter is the period that project-2 was introduced to the class, and students were focusing on understanding the concept of TIA, while they were developing their concepts. From another point of view, the third quarter of the semester was the most intense period of the semester for the students regarding the development of their skills and making progress in completing the project. During this quarter, students were grappling with developing the Design of TIA, designing and 3D printing the molds, and learning about the limitations of the machine on creating thin shells out of PLA and extruding alternative materials such as PVA.

4.2. Assessing final projects

After discussing the development of students' skills in various areas during the semester, project assessment and specifications are discussed in this section. All teams succeeded in having a stable and mortarless assembly of the topologically interlocking modules. Their projects were assessed based on three criteria:

i. Designing a block geometry with complex curvatures on all sides for mortarless assembly.
ii. Designing an assembly comprised of the blocks and iterating back if needed.
iii. Digital design and fabrication of plastic mold for repeatable casting of the block geometry.

All three projects fulfilled the first and second criteria. This was demonstrated through their successful installation at the end of the semester (Figure 7). All three projects achieved casting the modules through additively manufactured molds. 'The Wave' had mold parts that were all reusable, whereas 'Polyomino' and 'Re-Block' had reusable mold parts except for a core that needed to be melted to release the cast part. Table 3 summarizes the number of module types and the specifications of the molds that were designed in each project.



Figure 7. Final installation of the studio projects. Source: (Author 2024)

Table 3: Summary of the projects completed in the studio along with its mold design and fabrication specifications. Source: (Author 2024)

Project name	*Number of module types*	*3D printing material*	*Total number of mold parts.*	*reusable vs. sacrificed mold parts.*
The Wave	2	PLA	6	6 reusable parts (1 base, 4 walls, 1 plug).
Polyomino	1	PLA	12	11 reusable parts. 1 sacrificed part (the inner core).
Re-Block	1	PLA	4	3 reusable parts (3 walls). 1 sacrificed part (the inner core).

CONCLUSION

This manuscript demonstrates the production of lightweight concrete formwork using PLA only for the construction of discrete blocks that can be assembled without mortar through their topological properties. The topological interlocking blocks have complex curved surfaces on their perimeter, which makes constructing them very difficult through typical construction methods. Furthermore, many of the designed blocks have ornamental and intrinsics patterns on one side, which makes them impossible to be built through methods other than molding. Finally,

designing a reusable mold was a key consideration in the studio, to be compatible with the economics of scale towards a future circular economy. With advances in recycling plastics, utilizing plastic formwork for repeatable casting of complex building elements is a viable method. Regarding pedagogy, students were taught about 'employing 3D printing', as well as '3D printing technology itself,' through a project and problem-based learning. Students were introduced to AM technology from the beginning of the studio through a case study project. By the start of the second project — the design project — students' skills in AM technology had reached a 'very good' level that allowed them to effectively use that skill for developing the project. Ultimately, students pushed their learning about the limitations and opportunities of AM further by fabricating plastic molds during the third and fourth quarters of the semester.

ACKNOWLEDGEMENTS

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Enhancing Rammed Earth's Accessibility Through Novel Tectonic Machines: Developing and Testing a Rotational Tamper

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ABSTRACT: In the realm of accessible building technologies, rammed earth construction is a low-skilled, low-cost process of making architecture that commonly employs material found on site. This ancient construction process, where a loose earthen material mix in formwork is compacted with simple tooling, results in walls that are sustainable, healthy for inhabitants, and high-performance. Rammed earth walls offer functional compressive strength, filter air, capture and release heat, transpire moisture, become more durable with age, and are resistant to fire and infestation.

While anyone can skill-up to make rammed earth, the basic tooling and intensive labor involved can significantly tax and/or harm a builder's body. This form of *inaccessibility* can be off-putting to would-be earth builders, people who may not possess or who cannot afford the requisite calorie-intensive physicality to construct with rammed earth. The research detailed in this paper starts with the observation that rammed earth construction is associated with a technological evolution filled with gaps. In the current spectrum of rammed earth tooling/machinery there is significant space for machine development – new tooling/machines that operate between hand-tamping (low tech), and industrial-scale robotics and/or rammed earth "printing" (high tech).

With the goal of making rammed earth architecture more accessible by specifically addressing the requisite physical labor, a series of prototypical machines – Rotational Tampers – were developed and fabricated at 1:1 scale. These machines were tested in producing rammed earth walls and/or test samples for compaction, while monitoring the machine-user's heart rate as means of measuring expended energy in relation to tamping. In developing the machines, the researcher prioritizes *simplifying* the Rotational Tamper (easy to fabricate, assemble, and maintain), its *operation* (easy to set up, intuitive to operate, and easy to disassemble), and its *effectiveness* (producing quality rammed earth with less effort). Ultimately, the resultant Rotational Tamper(s) will be freely available as open-source plans/instructions.

KEYWORDS: Rotational Tamper, machine development, accessible rammed earth, low-calorie rammed earth, Tectonic Machines

INTRODUCTION

A common statistic associated with earth-based architecture is that approximately half of the world's population lives and/or works in buildings made of earth – many of these buildings are *self-built*, which implies a process done without the participation of an architect or professional contractors. Within the profession of architecture however, rammed earth has been gaining attention over the past decade thanks in part to the experimentations, constructions, publications, and consulting of Martin Rauch – who is essentially attempting to conventionalize or mainstream (un-stabilized) rammed earth as a building material (Rauch 2023). Additionally, well-known architects such as Renzo Piano (2020) and Herzog & de Meuron (2014) have used rammed earth in constructing buildings that have been widely published. While the benefits of using earth as a building material include good performance in measures related to sustainability, structure, human health, and ecology, there are also considerable problems to address. A partial (and paraphrased) listing based on one found in *Earth Construction: Lessons from the Past for Future Eco-efficient Construction* (Pacheco-Torgai & Jalali 2011) includes the following issues:

1. Lower durability of earth compared to conventional construction materials
2. Earth construction is labor intensive
3. Earthen constructions perform poorly in earthquakes
4. Earth budlings are structurally limited
5. Earth buildings might be considered high maintenance
6. Professionals make less money on earth-based projects
7. Special skills are needed for plastering (plaster prevents decay)
8. Earth is considered a non-standardized material re: building codes
9. Wall thickness is greater than other means of construction

The research presented in this paper addresses rammed earth's intensive labor. In the process of constructing with rammed earth, the requisite labor might be loosely categorized into three groupings: 1) earth material excavation and mix preparation, 2) formwork fabrication and/or formwork system assembly and disassembly, and 3) placing and tamping the earth mixture in the formwork. In this research, the author targets rammed earth's labor intensiveness, specifically in relation to *tamping*, through a gap in the technological development of tooling commonly used in rammed earth construction (Figure 1).

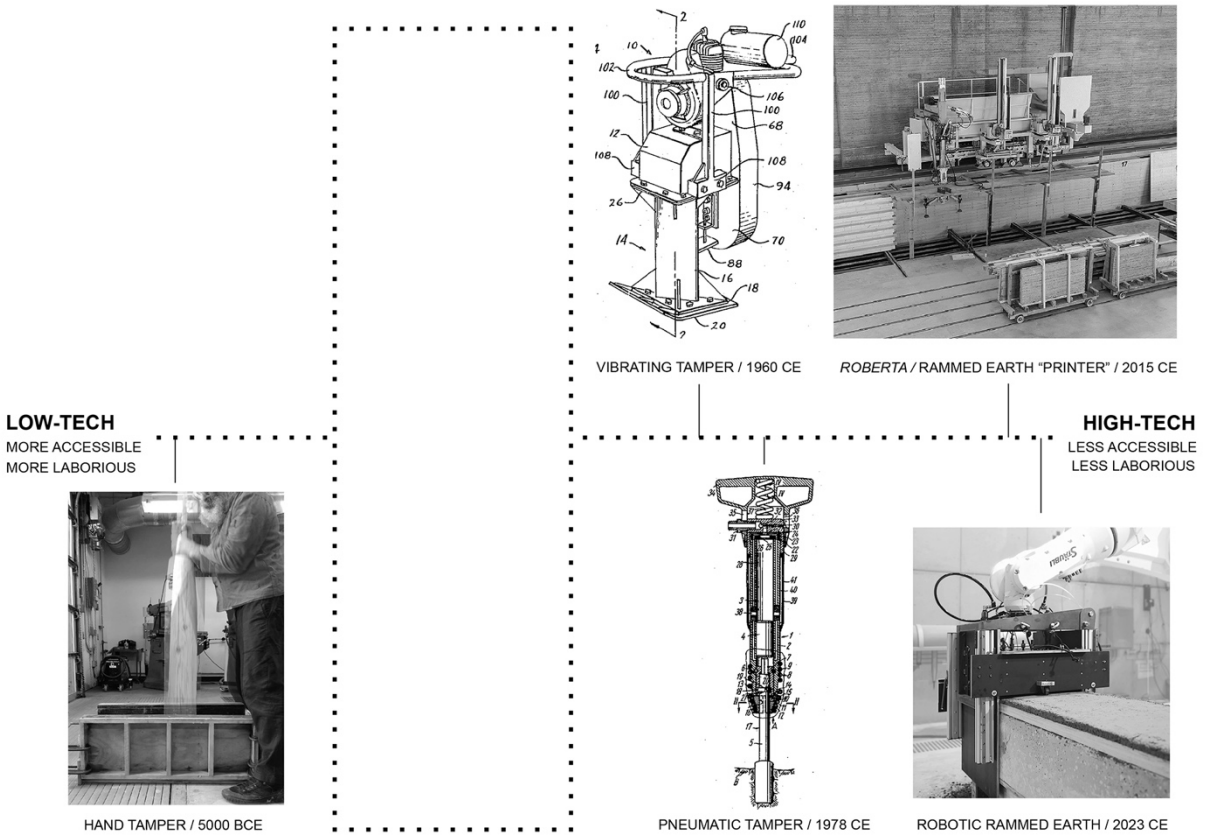


Figure 1*:* A considerable technological gap exists between the manual tamper as a low-tech tool (L), and high-tech mechanized means of ramming earth (R). This is a space for rammed earth technology development. Source: (Author 2023). Photographs at right used with permission: © Hanno Mackowitz & © Joschua Gosslar, Institute of Structural Design, TU Braunschweig. Patent drawings are opensource, USPTO. Hand tamper image, Author 2024.

This work begins with a hypothesis that simple machines reliant on body-activated mechanical advantage – rather than machines that are motor and fuel dependent – can be developed to significantly displace the labor burden associated with rammed earth tamping. Rammed earth builders today have three tooling options to employ when tamping, each one associated with different degrees of labor intensity: the *hand tamper* (essentially the same tooling developed in China 7,000+ years ago), *pneumatic tampers* driven by compressed air generators (gas or electric powered), and *modified industrial machinery* for manufacturing prefab rammed earth (e.g., manufacturing robots with special end effectors, or over-scaled earth *printers*). Of these options, hand tamping is the most accessible and the most labor intensive in that it requires the user to repeatedly lift and drop (or thrust) a weighted instrument as means to compact loose earth in a form. In building a wall, this action is repeated thousands of times, and the physical stress on builders can tip *laboring* into *suffering*. Pneumatic tamping is less accessible and less laborious but can cause serious vibration-related injuries in tool handling. Online occupational governance in California (and the UK warns of the potential harm caused by the *whole-body vibration* and/or *hand and arm vibration* associated with machines that transmit violent impact-compaction into the human body.[1] Pneumatic tamping also presents accessibility issues related to economics, requiring the purchase or rental of a tamping machine, air compressor, and onsite fuel or electric power. Additionally, these machines are quite heavy. Compared with these two options, factory-based industrial tamping machinery is significantly *not* accessible today. Capital, technology, heavy machinery, fuel, specialized labor, and transportation costs are all significant barriers to making this technology commonly accessible. One could add that coding/programing skills also represent a form of inaccessibility with these later technologies, as the machines are code-driven. In terms of labor, one can see specialized (skilled) labor and a high degree of mechanization/automation in high-tech rammed earth processes such as Lehm Ton Erd Baukunst's *Roberta* (https://www.youtube.com/watch?v=z5M7KG5EnB0), and in the manufacturing robot-based work being developed by Joschua Gosslar at TU Braunschweig (https://www.youtube.com/watch?v=X0v94Ejif_Q).

1.0 FULL SCALE EXPERIMENTS IN SIMPLE MECHANICAL COMPACTION

The work presented in this paper represents the development phase of research that investigates the use of simple machines to make rammed earth construction more accessible/less laborious. Research progresses along *proto-*

typological research methods proposed by Heisel and Hebel (2019), where "a full-scale application, that is an experiment and proof in itself" is used to evolve Rotational Tamping. In *Prototyping for Architects* (Burry & Burry 2016), the authors write, "Whether the prototype actually works or not is not the issue; prototyping is the *revelatory process* through which a designer gains insight into how well their experiment is proceeding. Failure offers important information which… increases the chances of a more successful outcome." In this research, the development of Rotational Tamping proceeds as iterative full-scale machine fabrications that are tested and measured, with research aims/goals informed by what succeeds and what fails.

The development of the Rotational Tamper began with a very simple mechanical idea – a heavy wheel. The earliest iteration of the Roto-tamper existed as a very heavy cast concrete wheel (400 kg) that was rolled into a braced formwork and then rolled back and forth while earth mixture was placed in the form cavity from above. The resultant earth was so overly compacted that it could be picked up as a beam (Bick 2016). Despite the effect of this concrete wheel as a hyper-compactor, two critical issues emerged during this preliminary test: 1) at the termination of the tamping phase, builders should not have to remove a very heavy (dangerous) object overhead from the formwork, and 2) the round shape of the wheel could not compact flat layers of earth at the termination of the formwork. At the ends of the constructed wall, the earth was not compacted, which meant that already vulnerable rammed earth corners and edges needed to be tamped by hand. Two additional iterations of the heavy wheel (RT-Zero Series B and C) where developed and tested (Figure 2); a concrete wheel in five parts (RT-ZSB) which allowed the heavy wheel to be disassembled in the form post-tamping, and a wheel made of an industrial drum (RT-ZSC) that could be filled with gravel before tamping, and then be emptied for removal from the form post-tamping. While these further iterations significantly addressed the issue of removing a heavy wheel from overhead in the form post-tamping, all three RT-Zero Series devices required significant conventional tamping at the ends of the resultant wall, which also impacts total labor requirements.

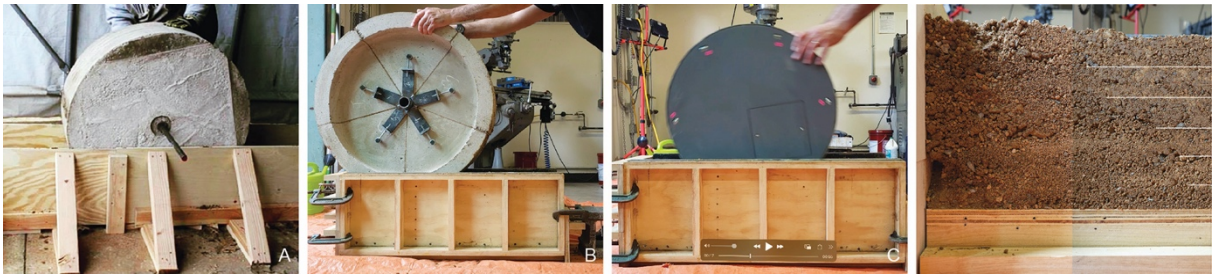


Figure 2: Three wheels/rollers foundational to Rotational Tamper development: A) 400 kg concrete wheel, B) a 180 kg concrete wheel that can be disassembled into five manageable parts, and C) a 77 kg wheel made of a steel drum and filled with gravel. While B and C solved the issue of removing a heavy tool from the formwork post-tamping, all three wheels were not able to compact earth at the ends of the formwork – a seen in the image on the right. Source: (Author 2023)

From these first experiments the researcher determined to move forward with something that rolled, as the concrete wheels had been relatively easy to move in the form. Other criteria that emerged from the concrete wheel test included 1) the idea of a "wheel" that was made of parts, one that could be assembled to tamp and then be taken apart atop a completed rammed earth wall, and 2) a wheel that included "stepping tamper plates" that could be manipulated to compact where parallel form side boards met the form bulkhead – resulting in compaction along the total length of the formwork. With these criteria articulated, the next iteration of the Roto-tamper (RT-01) was further informed by several outmoded pieces of technology (Figure 3): the *Dreadnaught Wheel* (1840+), a *Wheel for Road Engines* (1890) and the *Diplock Wheel* (patented 1900).

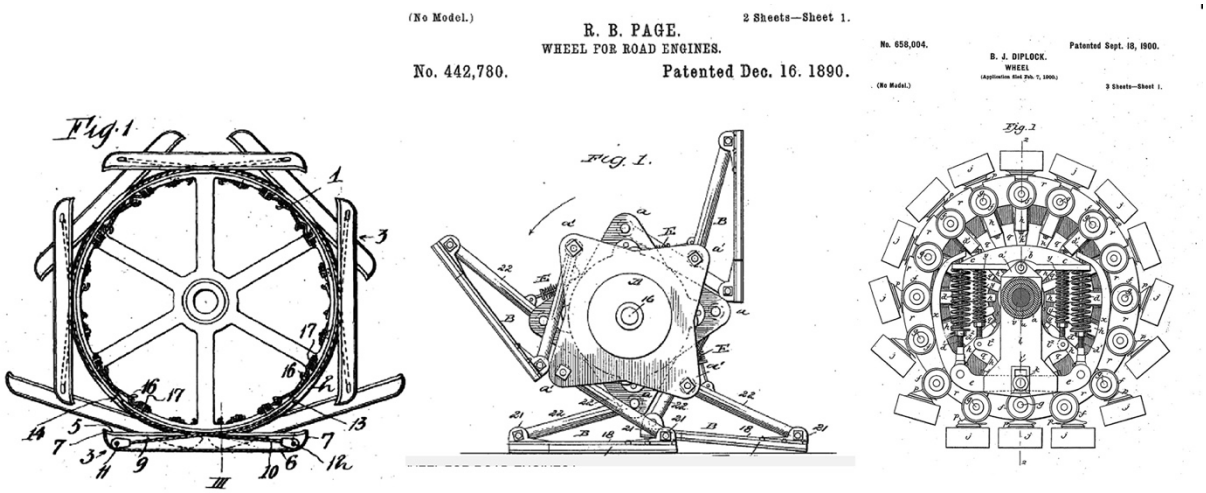


Figure 3: The *Dreadnaught Wheel* (L), *Wheel for Road Engines* (1890), and the *Diplock Wheel* (1900) are just a few outmoded technological means of moving heavy loads over unstable soil before caterpillar tracks became prominent in the 1900s. While not developed specifically to compact earth, these "walking wheels" as rolling/stepping compactors inspired the development of Roto-tampers 1 & 2. Source: (UK Patent Office and US Patent and Trademark Office).

1.1 Roto-Tamper 01

The development of the first Rotational Tamper (Roto-Tamper 01 or RT-01) took shape as a straight-forward eight-spoked wheel with large pivoting tamper plates on the end of each spoke. The spoke wheel was constructed using eight identical steel box tubes (7.7 cm x 7.7 cm). Rather than create complexity in fabricating the spoked wheel with angle-ended spokes as seen in the wooden prototype of RT-01 (Figure 4), the steel spokes are cut blunt-ended, and arrested in their angled positions with star-shaped plates. These plates were fabricated using a cnc plasma cutter, as were the triangular brackets of the tamper plates. In the production phase of RT-01 the researcher began to prioritize simplifying the design of the machine, use of common or stock pieces of steel, and the elimination of skilled fabrication methods (RT-02 would try to stay in the realm of metal cutting with saws or shears, MIG welding, cold work, and drilling holes). In future iterations, the use of the cnc plasma cutter as a fabrication tool would be eliminated. Fabricating RT-01 also required adding noise dampeners to each spoke, which eliminated a loud mechanical *CLANK!* caused by the tamper plates crashing into the spokes as the machine rotated (they also limited the swing of the tamper plate on the end of the spoke). Finally, to start, RT-01 had bearings positioned at the center of the spoke wheel – a feature carried over from the wheels that preceded this design. In RT-01, the difference between a rolling tamper, and a tamper that *steps* became clear… and the bearings at the center of RT-01 proved useless as RT-01 acted like a series of sequential levers rather than a wheel (RT-01's center moves up and forward in a rotating triangular motion as the machine is pushed through the form).

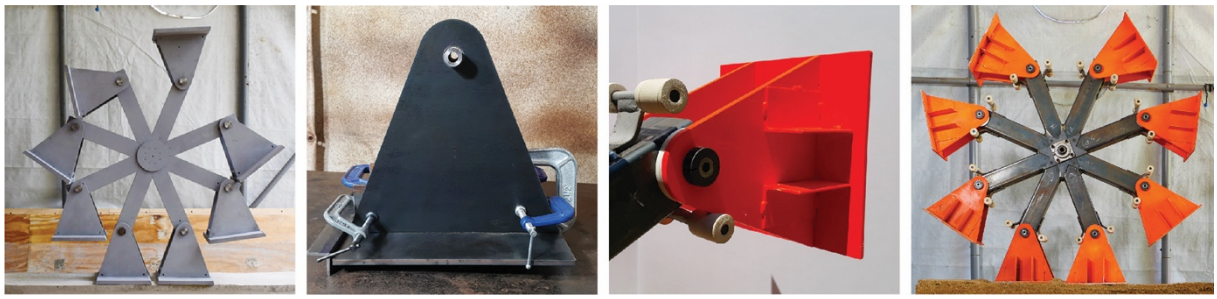


Figure 4: Roto-Tamper 01 evolved from a wooden prototype used to determine the overall dimensions of the various parts (L) to a steel machine that was employed to make a rammed earth wall test (R). Through this process, fabrication technologies were assessed for accessibility, and unforeseen components – such as noise dampeners – were designed on the fly. RT-01 did not actually roll, it stepped. Source: (Author 2023)

When the fabrication of RT-01 was complete, other unforeseen problems associated with Rotational Tamping emerged, specifically with the formwork. It is not uncommon for the sideboards of rammed earth formwork systems to be tensioned *through* the wall with tie rods, as the downward thrust of tamping can force the sideboards to push outward or bulge. In Rotational Tamping, the space of the formwork must be kept clear to allow for the back-and-forth passage of the machine. The Rotational Tamper also needs "overhang" space at the ends of the formwork cavity so that a tamper plate can act on material at the ends of the form. This necessitates formwork that can be tensioned from outside of the formwork cavity. The Rotational Tamping formwork cavity – as both the space that anticipates the rammed earth wall *and* a machine space, also necessitates that the machine user/wall builder is positioned outside of the form (it is not uncommon for rammed earth builders to stand inside formwork as they tamp the earthen material). In the realm of RT-01 formwork (Figure 5), one other unforeseen problem required immediate adjustment. The tamping plates of RT-01 (25 cm x 25 cm X .635 cm) were cut square, and their dimensions nearly match the width of the rammed earth wall anticipated in construction (+/- .635 cm). As soon as RT-01 began to operate inside the exterior-tensioned formwork, the downward step of the steel tamping plates began to destroy the top edge of the formwork sideboards. The immediate remedy was to dismantle the formwork sideboards and cut away the top inside edge at 30°. As of this writing, the development of appropriate Rotational Tamping formwork still requires attention.

In constructing the first rammed earth wall with a Rotational Tamper, the researcher made a preliminary wall that employed climbing formwork (a small vertical section of formwork that moves up with the tamping). This process was quickly abandoned in favor of a full-wall formwork as to better support the externally tensioned formwork on a concrete footer, and to contain any unforeseen effects of vibration caused by the stepping machine while making the first wall test. The second attempt at RT-01 Wall proceeded without further incident, with the machine user (a 53-year-old male with conventional rammed earth construction experience) monitored for heart rate (HR) specifically while tamping (heart rate results appear in section 2.1). While constructing RT-01 Wall, it was observed that the machine operator should use the uppermost tamping plates as "handles" to step the machine back and forth through the form, and to "jog" the machine (a micro movement) when tamping at the ends of the form. It was observed that a person using the spoke as a control lever could have his/her arm dragged into the form, where it could be caught between the top edge of the formwork and the following spoke (carried by momentum). Keeping hands on top of the machine (using tamping plates as push points) became a safe operation requirement and initiated a revision to the wheel component in RT-02. When RT-01 Wall (304.8 cm x 26 cm x 198 cm) was completed, RT-01 was dismantled from atop the form/wall, and each piece was passed to the ground. Dismantling the machine took five minutes (Figure 6). Each RT-01 tamping plate weighed 7.7 kg, the spoke wheel weighed 29 kg, and tamping plate hardware sets (one axle, two shaft collars) weighed .5 kg.

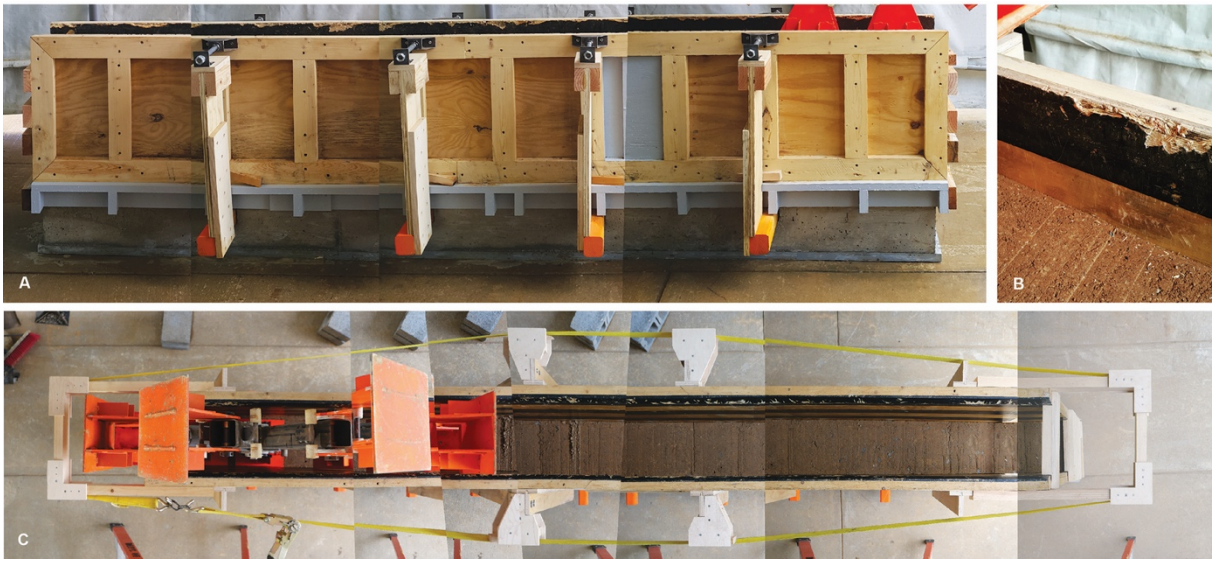


Figure 5: A novel machine for ramming earth requires formwork that is also somewhat atypical. Rotational Tamping formwork required external means of tensioning the sideboards of the formwork. At the lower level of the form this was achieved with mechanical adjusters that put inward pressure on the form (A). As the rammed earth wall grew and more layers of formwork were added, the top layers of the formwork were tensioned with heavy duty ratchet straps and wedges, as seen in the plan view (C). RT-01 also shredded the top edge of the formwork (B). Cutting it away at an angle allowed the square steel tramping plates to ease into the form rather than collide with the top edge as they entered the form cavity. Source: (Author 2023)

1.2 Roto-Tamper 02

At the start of the discussion of Roto-Tamper 02 it is important here to emphasize the researcher's desire to simplify the machine. The design and fabrication of RT-02 would be kept within a realm of common/simple metal working skills and common metal parts/hardware employment. Engineer Raul Ramírez's CINVA Ram (1952-1956) appears here in the research as a model/ideal simple machine that eased the physicality/labor burden of making earthen block in contrast to blocks laboriously hand-pressed in wooden forms (Figure 7).

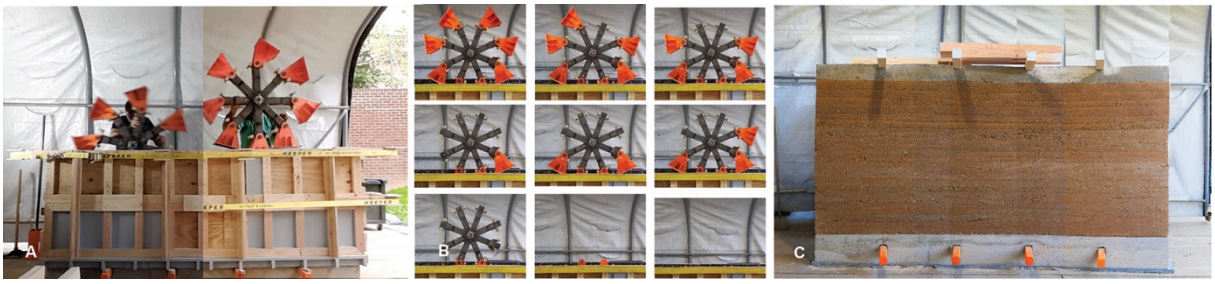


Figure 6: (A) Composite images from video show RT-01 Wall being constructed, the machine rising out of the formwork as the earth is tamped in layers. In both stills, the machine operator is using the spokes as levers/operating handles – this was determined to be an operational hazard (and design flaw) in RT-01. (B) RT-01 is easily dismantled when the wall is complete. The weight of each part becomes a key factor in further machine development, as overall weight effects compaction capacity, while part weight determines who can dismantle the machine safely. (C) RT-01 Wall completed. Source: (Author 2023)

The CINVA Ram and other more simplified manual block presses are designed around an ethos of *easy to manufacture, easy to maintain and repair.* The accessibility component that is at the essence of the Rotational Tamper should also include *fabrication skills access*, *manufacturing technology access*, and a certain obviousness in assembly/repair that translates into *accessible maintenance*. Additionally, there is a tectonic thinking/skills-transmission component built into the CINVA-Ram that also influences the Rotational Tampers. These machines – *Tectonic Machines* – enable builders with no-to-little skill to create intelligent architectural components, blocks, walls, etc., through direct engagement with the tooling. As a novice builder receives blocks of a certain thickness and dimension from the compaction chamber of the CINVA-Ram, block dimensions that have been deemed easy to handle, appropriate in size to the material, and appropriate in their material volume to support wall-building, so the tamping plate dimensions of the Roto-tampers, their obvious compaction capabilities, and linear movement represent a prescription of sorts – in machine form – for linear rammed earth wall making. Tectonic Machines enable users to manufacture architectural elements that are specifically proportioned, incorporate a specific material knowledge, provide for a degree of variety in architectural form, and extend the skill and physicality of the (Shaffer 2009).

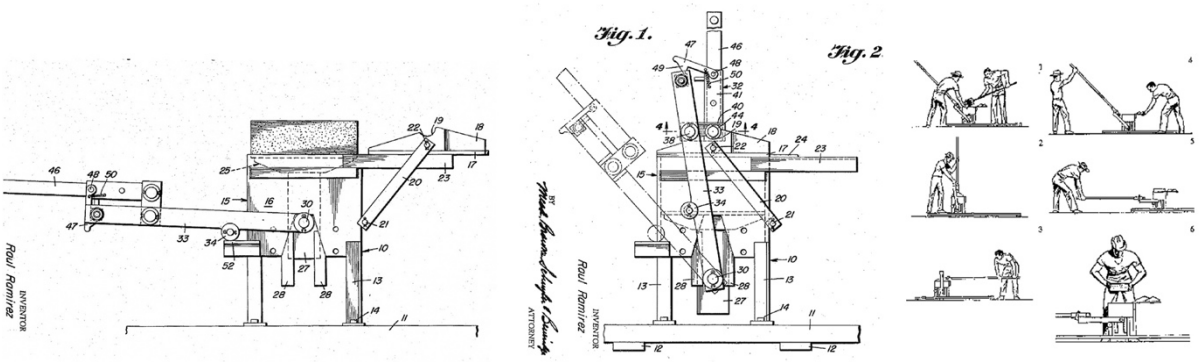
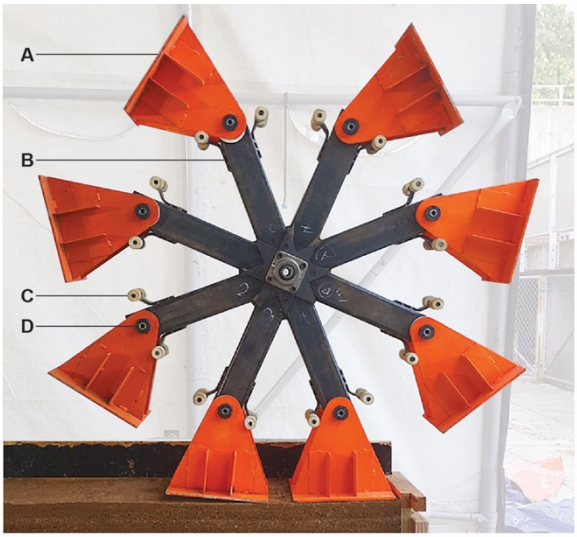
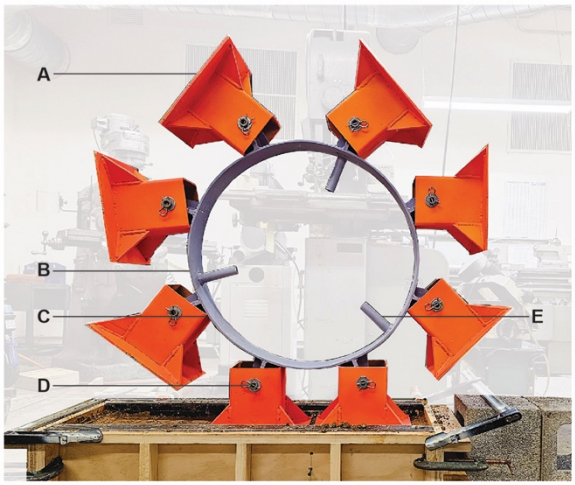


Figure 7: The CINVA Ram is a simple machine that significantly changed the labor investment in making high-quality earthen block. While the images above do not convey simplicity, the machine does not require high skill to make, operate, or repair. By easing the labor required to make earthen block and anticipating the level of skill to make/use/repair the machine, Raul Ramírez addresses *accessibility* at multiple levels. Source: (US Patent & Trademark Office 1960, IBEC Housing Corp. NY 1959)

In comparing Roto-tamper 02 to Roto-tamper 01 (Figure 8), several design changes connect to simplifying the machine for increased accessibility. Other design changes address safety and/or machine operation. In addition to the specific changes listed below, RT-01 measures 126 cm in diameter and weighs 94.6 kg, while RT-02 is smaller, measuring 100 cm in diameter and weighing 100.3 kg. RT-02 was easy to "step" back and forth in the formwork, was less prone to tipping as it completed the last layers of rammed earth at the top of the formwork, and was generally less dangerous to operate, as the potential for the machine user's arm to be trapped between a spoke and the top of the form was eliminated with the open center of the band/wheel component in the RT-02 design. A significant redistribution of the total weight of the machine meant that no part of RT-02 weighed more than 12.5 kg (the spoke wheel of RT-01 weighed 29 kg, which violates a threshold for occupational lifting limits (25 kg). At this point in the research, Roto-tamper 02 has only been used to tamp a small preliminary wall sample measuring 92 cm x 27 cm x 27 cm. Testing the machine in constructing a full-scale wall (304.8 cm x 26 cm x 198 cm) will begin in SP 2024. Producing the smaller wall sample allowed the researcher to test the effectiveness of the machine, measure the machine user's heart rate (HR) as an indication of labor invested in tamping, and produce an earthen sample for testing under compressive force.



ROTO-TAMPER 01
A: CNC plasma-cut brackets connect tamping plates to spoke wheel
B: Spoke wheel supports tamping plates from the center of the machine
C: Dampeners eliminates clanking and control tamping plate swing
D: Axle connection is secured using two shaft collars



ROTO-TAMPER 02
A: Short lengths of standard box steel connect tamping plates to wheel. They are filled with ballast to give the machine weight. The RT-02 plates have tapered edges so that they might enter the form cavity without damaging the formwork
B: A 10.16 cm wide slice of steel pipe (wheel) bands the tamping plates together
C: Careful placement of the tamping plate in relation to the wheel controls swing
D: Axle connection is secured using cotter pins
E: Short pipe handles are added to the inside of the connecting band/wheel as a form of micro-control

Figure 8: RT-01 compared to RT-02. Design of the second machine is directly informed by fabrication of RT-01 and the subsequent testing of RT-01 in construction of a full-scale rammed earth wall. Source: (Author 2023)

2.0 FINDINGS

Two areas for measuring the effectiveness of Rotational Tamping were addressed through the construction of rammed earth samples; energy expended in the labor of Rotational Tamping, and strength testing of rammed earth samples produced using the machines. For the sake of comparison, the researcher also recorded the expended labor required in using a hand tamper to ram earth, and in using a pneumatic tamper. Similarly, rammed earth samples made using a hand tamper and a pneumatic tamper were strength tested for comparison against earthen samples produced with Rotational Tampers.

2.1. Measuring expended energy invested in rotational

In recording heart rate (HR) information, the constructor wore Fitbit™ technology, and wile tamping, his heart rate was recorded every minute until the rammed earth sample was completed (tests began at a "resting" heart rate). The heart rate information associated with each ramming technology was recorded as mean/average, with peaks or spikes also recorded. In the table below (Table 1), heart rate recordings from four different tamping technologies (hand tamping, pneumatic tamping, and the two Rotational Tampers featured in this paper) are compared against a metric of cardiovascular response to construction *work* (Abeelhamid and Everett 2002). Findings from this assessment show that Rotational Tamping can be classified as *moderate work* compared to the *heavy/very heavy work* of hand tamping, and in comparison, to the *heavy work* of pneumatic tamping.

TABLE 1: Cardiovascular Response to Prolonged Physical Work Compared to Various Means of Rammed Earth Tamping. Source: (Adapted from Abelhamid and Everett 2002)

			HAND TAMPING		PNEUMATIC TAMPING		RT-01 TAMPING		RT-02 TAMPING	
WORK SEVERITY	MEAN HR	PEAK HR	MEAN / PEAK HR		MEAN / PEAK HR		MEAN / PEAK HR		MEAN / PEAK HR	
VERY LIGHT WORK	N/A	UP TO 75								
LIGHT WORK	UP TO 90	75-100								
MODERATE WORK	90 - 110	100 -125					97	108	95	111
HEAVY WORK	110 - 130	125 - 150	129		111	114				
VERY HEAVY WORK	130 - 150	150 - 175		136						
EXTREMELY HEAVY WORK	150 - 170	OVER 175								

NOTE: SOURCE: ADAPTED FROM ABELHAMID AND EVERETT (2002).

2.2. Measuring effectiveness of rotational tamping in ramming

In assessing the effectiveness of Rotational Tamping to construct rammed earth the researcher produced eight rammed earth samples using four different tamping tools/machines: a hand tamper, a pneumatic tamper, RT-01, and RT-02. The resultant samples were all the same dimensions (26 cm x 26 cm x 24 cm), were made using an identical earthen mix (local clay and shale-heavy earth, gravel, coarse sand, water), and were dried for thirty (30) days in the same environment. To compare the level of compaction across all the samples, each one was subjected to compressive force using the same 10-ton metered hydraulic press (Figure 9). The performance of each sample under mechanical compression was recorded (Table 2). Findings from this assessment show that the Rotational

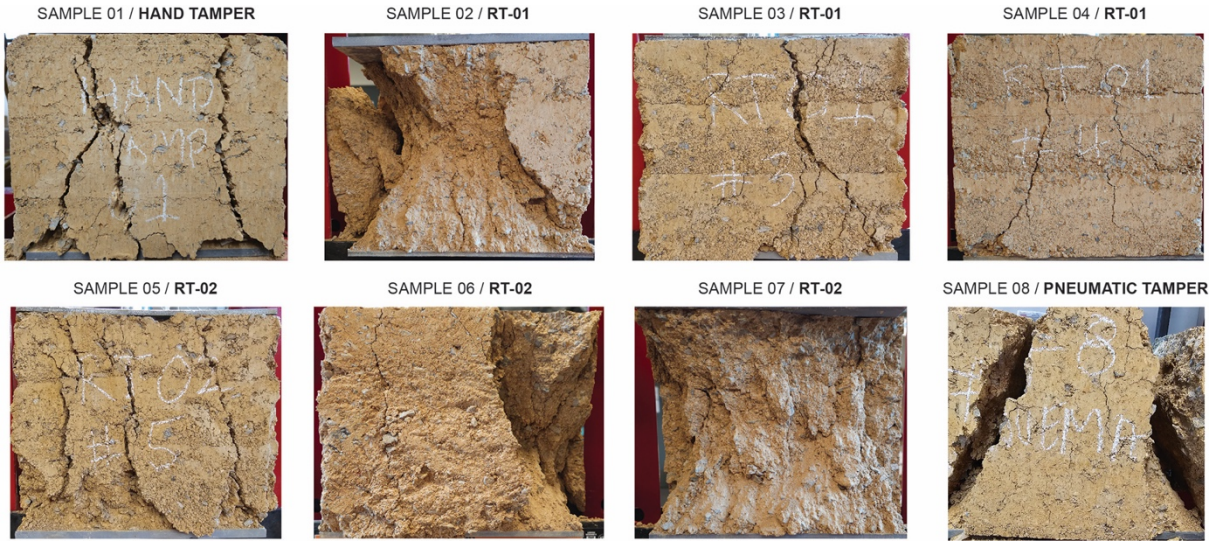


FIGURE 9: Samples used to compare the effectiveness of RT-01 and RT-02 in ramming earth. Source: (Author 2024)

Tampers compact earth to a degree that is as good as, if not slightly better than tamping by hand. Samples made by Rotational Tamper 02 are comparable to the sample made with a pneumatic tamper. These tests – using larger samples – will be repeated using more sophisticated compression testing equipment.

TABLE 2: Comparison of Rammed Earth Sample Compaction Source: (Author 2024)

	SAMPLE 01 / **HAND TAMPER**	SAMPLE 08 / **PNEUMATIC TAMPER**	SAMPLE 02 / **RT- 01**	SAMPLE 03 / **RT- 01**	SAMPLE 04 / **RT- 01**	SAMPLE 05 / **RT- 02**	SAMPLE 06/ **RT- 02**	SAMPLE 07/ **RT- 02**
FRACTURED	4.1 mt	6.9 mt	5.0 mt	5.1 mt	5.3 mt	6.2 mt	6.1 mt	6.5 mt
FAILURE	6.1 mt	7.6 mt	6.2 mt	6.3 mt	6.2 mt	7.1 mt	7.9 mt	7.7 mt

CONCLUSION

Rammed earth is an accessible form of construction that is employed globally; commonly using earthen material excavated from a building's site to construct walls that are strong, durable, and healthy for inhabitants. While

rammed earth has a long history, its technological development is characterized by a significant gap between simple, accessible hand ramming tools and less-accessible mechanized tooling that includes vibrating/compacting machines, industrial robots, and factory-scale earth “printers”. Another characteristic of rammed earth construction

is its labor intensiveness, with significant labor (heavy and or very heavy) required to ram earth when using hand tools and hand-held mechanized tooling. The development of Rotational Tampers for constructing rammed earth walls – simple machines closer to hand-tamping tech/tooling than pneumatic tamping machines – represent an attempt to make rammed earth construction more accessible by displacing the requisite labor into simple machines. Preliminary research presented in this paper, including heart rate monitoring during construction and compaction testing of rammed earth samples, indicate that Rotational Tamping reduces the *heavy* and/or *very heavy* work of tamping by hand or with pneumatic tooling to *moderate* work. Additionally, rammed earth samples created by Rotational Tampers compare in strength to samples created by hand tamping and pneumatic tamping. Compared to hand tamping, the Rotational tampers appear to produce rammed earth that is stronger. Compared to pneumatic tamping, the Rotational Tamper 02 appears to produce rammed earth that is similar in compaction.

The development of Rotational Tampers includes both machine design and rammed earth construction. The research will benefit from repeated rammed earth wall building tests that include a wider range of machine operators – female and male builders whose age and strength varies from teenagers to builders in their 60s. These tests will focus on the simplicity of the machine (to fabricate, assemble, disassemble, move, repair), operating the machine (easy, intuitive and safe to use), and the effectiveness of the machine (producing quality rammed earth walls using less labor). Both of the Roto-tampers in this paper were essentially built with scrap metal. Rotational Tamper 03 will factor in material cost and fabrication hours, and a recording of skills/skill level used in the fabrication process – additional factors to be considered in making rammed earth more accessible.

ACKNOWLEDGEMENTS

This research is a continuation of architectural thesis work done by Zoe Bick, and advised by the author, in 2015-16. Zoe’s thesis, “Mechanizing Rammed Earth: Making New Earth Construction in the US” can be viewed here: https://etda.libraries.psu.edu/catalog/29163

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Curved-crease Cardboard Origami: A Framework for Modular Deployable Cardboard Structures

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ABSTRACT: This paper explores the use of curved-creased Origami to create complex architectural forms from corrugated cardboard. Curved-creasing blends folding and bending through curvilinear creases, transforming flat sheets into load-bearing 3D structures. While this technique has been applied to materials like paper, aluminum, and plywood, its potential with cardboard remained unexplored. The study used digital simulations, physical prototyping, and mock-up assemblies to test ten design templates, focusing on minimizing cuts, avoiding wrinkles, and ensuring structural stability. While simulations predicted stress points, physical prototypes revealed that cardboard naturally releases stress through wrinkles along its corrugation channels. To address this, researchers introduced supplementary and stress-releasing fold lines, controlling deformation while enhancing the material's aesthetic qualities. Findings demonstrate that curved-creased Origami can expand the architectural potential of cardboard, offering a sustainable, low-carbon alternative for design applications.

KEYWORDS: Curved-creased, origami, cardboard, modular, lightweight

INTRODUCTION

Current efforts in the building industry are directed towards reducing its carbon footprint and negative impacts on the environment. Alternative construction materials, such as corrugated cardboard, have great potential due to it being highly recyclable and inexpensive (Schütz 2018; Latka 2017). Carboard has been popularized as a building material by architect Shigeru Ban and can be used to build active vector structures such as columns and beams, and active surface structures like folded panels and wall (Diarte and Shaffer 2021). Surface active structures include folded flat cardboard surfaces, whose efficiency depends on the form of the surface in relation to the forces applied to it. Curve crease folding, unlike traditional Origami composed by straight-line folds, utilizes curvilinear creases to create complex three-dimensional forms. Curve-creased folding has been used in several materials such as paper, metal and composites; however, much less is known of the potentials of this technique to create inexpensive deployable structures with corrugated cardboard. This study seeks to fill this gap by developing and testing fabrication workflows for curve-creased corrugated cardboard deployable structures.

The work presented in this article is based on and expands upon two threads of the literature: First, on the use of Origami and curved Origami for developing architectural systems. Second, this study also contributes to the literature of cardboard as a resource for designing and fabricating low-carbon building systems. The next few paragraphs provide an overview of these two areas of inquiry.

Origami has been a source of inspiration in architectural design as not only a way to construct aesthetically appealing forms, but also as form finding technique for deployable structures. Origami folding allows for creating complex three-dimensional structures from flat sheets and can be designed to achieve desirable material properties such as auxetics, nonlinear, and multi-stability (Li et al. 2019). Additionally, Origami and Kirigami shapes can exhibit enormous resistance to support loads. Previous research done by Wang et al. (Wang et al. 2020), for example, designed an interweaved Kirigami extension assembly with paper, and after different mechanical tests discovered its super strength–load to weight ratio around 10^4–due to the in-plane compression resulting from the overlapped flaps. The most used techniques in Origami rely on straight lines as in the Miura-ori pattern used by Liu et al. (Liu et al. 2015) and comprehensively studied by Miura (Miura 2009). There is also no-crease folding technique by Jackson (Jackson 2011) aimed at creating complex convex to concave curves on paper and later translated to aluminum sheets by Patkau et al. (Patkau et al. 2014). Curve creased folding on the other hand, makes use of curvilinear creases to guide the sheet fold, resulting in a hybrid between folding and bending, unlike traditional Origami which is pure folding (Demaine et al. 2011). David Huffman's curve creased models are perhaps one of the most well-known early examples of this technique –for instance, his Hexagonal Column with Cusps also shown in (Demaine et al. 2011).

In architectural design, curve-creased folding has been used in a variety of applications. The designs can be divided into kinetic and static building components. In the first group, curve crease folding is used as the base geometry for shape-morphing structures, which enables complex geometric transformation. Examples of kinetic systems using curve-creased folding are the climate-responsive facade system by (Tahouni et al. 2020) using 4D printing, an adaptive facade shading system by (Vergauwen, De Temmerman, and Brancart 2014), and Flectofod –a compliant shading device by (Körner et al. 2018). The second group of applications are the static building components that

make use of curve-crease folding. One well-known example is the multi-panel sculpture by Zaha Hadid Architects at the Venice Biennale 2012 (Bhooshan et al. 2015), which implemented a form-finding method for curve-creased geometries in the fabrication of 500 metallic panels. Another case in which curve-line folding is used to develop (static) building elements is seen in the curved-Origami timber panels by (Buri, Stotz, and Weinand 2011) showing that this technique is also possible to implement in wood. A subgroup in the static applications can be established with curve-creased formwork examples, where the technique is not used for developing finished building components, but rather, to fabricate three dimensional formworks from flat materials such as wax paper (Lloret‐fritschi et al. 2022) or plywood and textile hinges (Scheder-Bieschin, Van Mele, and Block 2022).

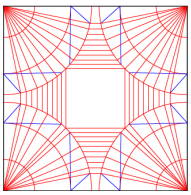
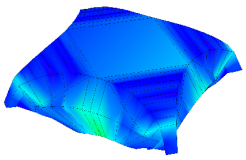
In terms of cardboard, researchers have argued that this material is a lightweight, inexpensive, environmentally positive material for architectural applications (Van Dooren and Verheijen 2008; Łątka et al. 2022). Cardboard structural systems can be broadly classified into active vector and active surface structures (Latka 2017; Diarte and Shaffer 2021). Active surface structures include flat and folded surface elements, such as folded panels, cardboard blocks, and cardboard panels. The folded surface category in cardboard architecture includes Origami folding, an example of this seen for instance, in the cardboard pop-up dome, a lightweight and transportable cardboard structure designed as a multi-use shelter by Latka (Latka 2018). Origami folding techniques can be used to transform flat carboard sheets into lightweight, spatial, and aesthetically appealing self-standing structures: A challenge in using carboard in Origami folding, nevertheless, is the thickness of the material that constrains folding angles, as noted in (Tachi 2011). Curved crease folding, however, has scarcely been explored for cardboard architecture. One example of curve-folding is the curved-fold dome, a geodesic dome made with curve-folded struts (Latka 2018).

The review of the literature highlights opportunities to expand on existing methods for curved crease folding and cardboard architecture. Several studies have characterized material behavior and presented curve-creasing methods for different materials such as wood, metal, and composites; Cardboard, however, remains largely unexplored. There is a need to develop workflows for transforming flat corrugated cardboard into deployable systems using curve-creased folding to expand its application in architecture. Another critical challenge in using corrugated cardboard for curved line Origami folding is the anisotropic nature and structural directionality dictated by internal flutes, which results in different properties when folded according to the folds' relation to the inner channels' axis.

1.0 Materials and Research Methods

The study started empirically by designing curve creased Origami patterns to make a modular 3D assembly with corrugated cardboard sheets for a temporary indoor construction. The design process included traditional techniques (e.g., hand and digital-made drawings and scaled paper models) and we then implemented quantitative and experimental research methods to assess the process and determine how to improve design and increase fabrication efficacy. Based on the architectural research methods framework proposed by Müller (Müller 2021), the quantitative part of the work relied on digital modeling and simulation using Grasshopper for Rhinoceros 3D and an interactive Origami simulator[1] correspondingly. The experimental part relied on physical prototyping and full-scale construction testing. Table 1 below summarizes details of the methods employed in the study.

Table 1: Research Methods. Source: (Authors 2024)

			
	Prototyping (Experimental)	Simulations and modeling (Quantitative)	Testing (Experimental)
Goals	Experiment with curved-creasing patterns to fold corrugated cardboard sheets	Investigate and digitally visualize strain occurring on corrugated cardboard sheet due to different types of curve-creased folding angles and patterns.	To build a mock-up of a 3D assembly and asses the construction process.
Study set-up and/or data sources	Digital: Rhino 3D Grasshopper Physical: Fabrication lab set-up using a KUKA robotic arm with a customized creasing wheel.	Digital simulations made with Origami Simulator app by Ghassaei et al. (2017)	Indoor exhibition space and shop at the University of North Carolina at Charlotte, School of Architecture in the USA.
Data collection	Video and photo recording.	Results presented in graphical format and exported as image file.	Video and photo recording.

Data analysis	Visual assessment of strain effects on 3D assemblies for correction of design patterns as well as evaluation of robotic creasing process.	Graphics collected from simulations where visually analyzed.	Observations of assembly process with special attention to procedure, techniques, and tools. Assessment of supplementary building components used in the process.

1.1 Simulation

After designing the Origami pattern in Rhino3D, we simulated the folding process using an interactive Origami simulator. The open access web-based app created by Ghassaei, Demaine, and Gershenfeld (2018) simulates any Origami crease pattern in real-time and helps to understand how it affects the folding. The simulator opens SVG or FOLDS format files and folds paths following a defined stroke color (e.g., red for mountain folds, blue for valley folds, and black for boundary edges) illustrating the axial stresses across the sheet[2]. Stresses are shown in blue (no strain) to red (high strain). We increased the default face and fold stiffness from 0.2 to 1.0 and 0.7 to 1.0 in the simulation settings, assuming cardboard is a much more rigid material compared to regular paper.

1.2 Design and fabrication requirements

A list of prototyping requirements was established in advance to measure whether a particular design was successful or not. These requirements included material and aesthetical criteria such as minimizing the number of cuts on the cardboard sheets, minimize wrinkles after folds, avoid tearing sheets, and facilitate joins between modules to create a potential larger structure. Prototype fabrication requirements included using a tool consisting of a custom-made creasing wheel attached to a robotic arm, no gluing to mount the modules, making a single module per each cardboard sheet, and minimizing waste. All prototypes were made using general purpose and single wall corrugated cardboard pads with flute type C, 4 mm thickness, and 1200x1200 mm dimension3. The selection of this cardboard type was because it can be found anywhere for replicability and strength—its use to provide layers to separate and protect heavy goods of up to 90 kg.

Moreover, inspired in the creasing wheel tools for CNC cutting machines typically used in the textile and packaging industries, we fabricated a custom-made creasing tool with leftover material from the metal shop. We repurposed a 50 mm diameter and approximately 2 mm thick aluminum washer for the wheel and two bearing wheels, a few rubber rings, a 60 mm long aluminum pipe for the shaft, 150x50 mm aluminum profiles, and bolts for support and robot attachment. The main washer-wheel spined freely when the robotic arm moved back and forward, and the angle formed with the cardboard sheet was always 90 degrees. Figure 1a and 1b below shows the initial design and fabricated tool used for the study.

1.3 Template design

Figure 1c illustrates the concept for the cardboard module with three basic parts each on a different color (front, side, and back). The goal was to build a four-point star starting from a square cardboard sheet. The sheet corners would be folded following a series of curved creases and the least number of cuts. The size, position of the curves and distances between them was unknown as well as how many other creasing or cutting lines would be needed to appropriately fold the module. Experimenting with these parameters was the starting point of the prototyping phase.

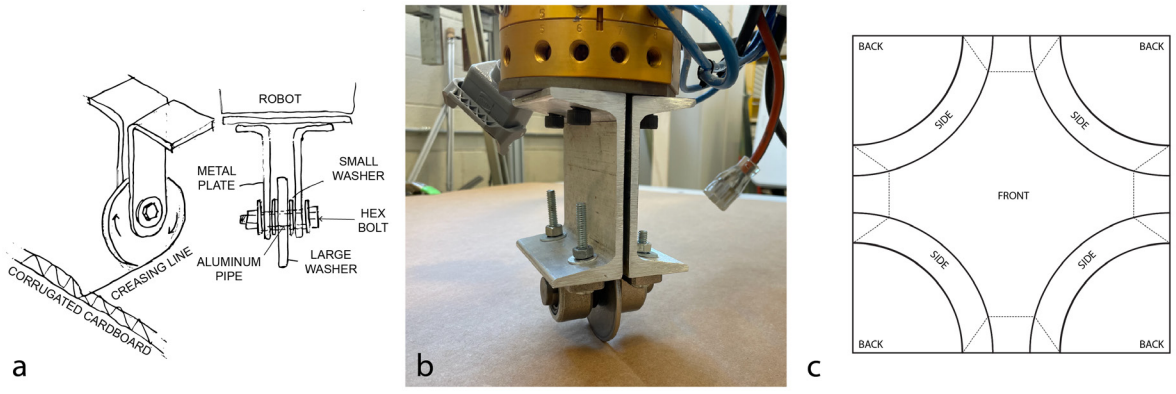


Figure 1: Custom made creasing tool at initial design (a) and final tool (b) and creasing concept (c). Source: (Authors 2024)

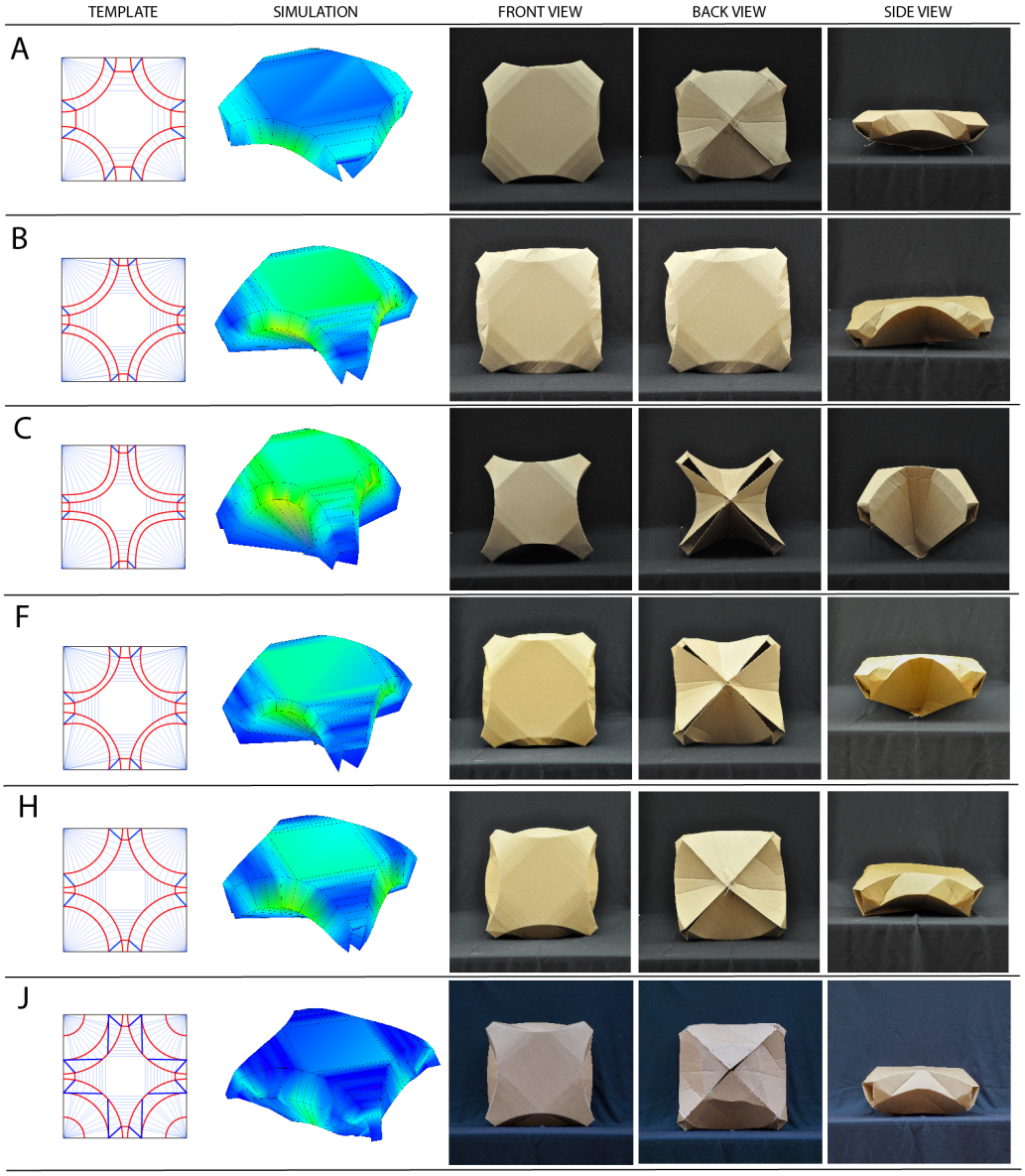
2.0 RESULTS AND DISCUSSION

2.1 Prototypes fabrication features

In total, ten template iterations were developed, all of them from cardboard sheets with dimensions 1200x1200 mm. Table 2 illustrates a selection of the most representative including a simulation preview, front, back, and side views of assembled modules. Prototype A parameters were defined intuitively, considering it was the first template of the set. We wanted the tips of the star to be flat not pointed to ease the joins with other modules, so they were approximately 140 mm wide and the offset between the arcs (red mountain folds) on each corner was 115 mm

aiming to give a sizable thickness to each module. After observing the simulation, several blue valley folds were intuitively added to decrease potential face stiffness, especially in the sides and back were strain looked high. We decided to pass the tool twice on the red mountain folds because these are the main folds of the design: the blue valley folds are supplementary folding lines that help guide the folding. Prototype A front, back, and side views show a relatively well-formed module and well-defined star ends; however, the folds in the front were too pronounced and those on sides were uneven and too sharp. In addition, there were several unwanted wrinkles or folds to the side of the module (see prototype A-side view).

Table 2: Prototypes comparison. Source: (Authors 2024)



Experiments for prototype templates B through F sought to study the creasing effects of the arc geometry—here we include images of B, C, and F only. Arcs in these templates have different curvatures and offset distance between them vary from 55-85 mm, the flat end of the star is only 85 mm wide and all of them have 30% more blue valley folds than the first prototype. As it can be seen in the pictures, semi-circular arcs as in prototypes B are easier to fold but even though more blue valley folds where added, the tessellation created on the sides is still uneven. On the other hand, parabolic arcs as in prototype C creates a well-defined front view of the star shape module; though, it isn't possible to completely fold the sides producing a bizarre shape. Prototypes F is template sample that combined semi-circular and parabolic arcs, but still no major improvements were achieved.

Prototype H represent another group of templates with semi-circular arcs separated 135 mm and 85 mm wide flat star ends. Although they were easy to assembly and their front view looked even, the sides had the same problems as in the previous prototypes. Consequently, for the last prototypes, J is a typical example of this group, we added a few orthogonal blue valley folds to release the stresses in the cardboard and purposely guide the folds on the sides. These extra valley folds made a significant difference on how the sides looked. Additionally, prototype J included a minor semi-circular arc in the corners to create a flat surface on the back (see J's back view) and this was the module used to test the mock-up.

2.2 Simulations

Simulations were relatively good on predicting cardboard's behavior. In general, the low strain showed in some prototypes was corroborated during the folding process; however, certain stresses that appeared on the side weren't evident and only visible when assembling the modules. This could probably be solved by correcting the face and fold stiffness simulation settings to get more accurate results. In this regard, an interesting aspect we discovered during the process was the importance of not relying only on the simulation to decide whether to proceed with a template design or not. Both simulation and physical template provided with useful information to take decisions so we would recommend working with both constantly. Figure 2 below shows some examples of problematic stresses that did not show on the simulation but appeared in the physical prototype assembly. Unwanted creases or folds in prototypes G and F and identified in Figure 2a-b with numbers 1, 2, and 3 were solved in prototype J by adding extra valley folds identified in Figure 2c with numbers 4 and 5.

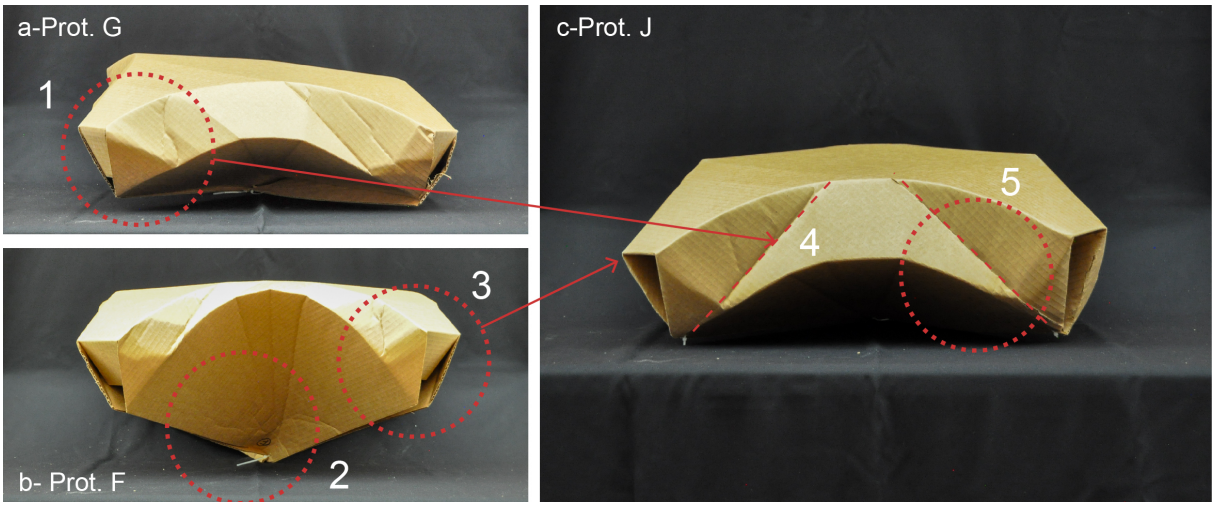


Figure 2: (a-b) Problematic stresses in prototypes G and F and (b) solutions applied in prototype J. Source: (Authors 2024)

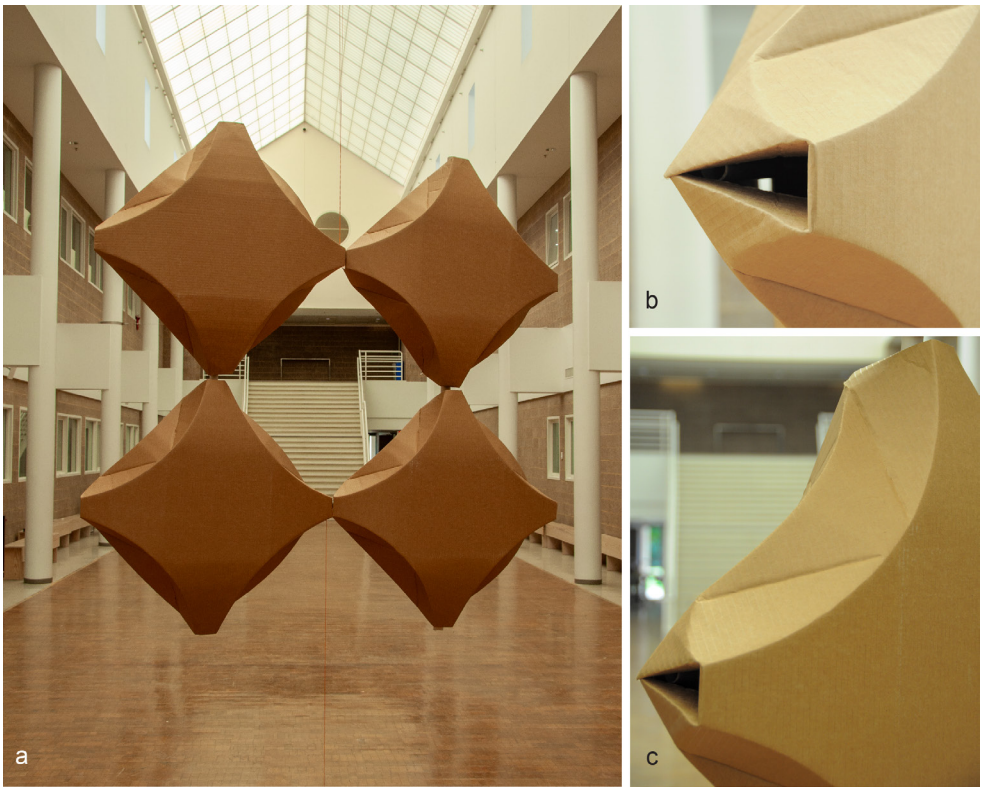


Figure 3: Assembled mock-up with four prototype J modules (a) and folding details (b and c). Source: (Authors 2024)

2.3 Mock-up assembly

Finally, we assembled a structure made with a few modules to test how to connect them (Figure 3a) and explored the aesthetic and spatial qualities of the material system. We then took four prototype J modules, some repurposed PVC pipes 25 mm diameter, plastic ties, and thread. We cut four pipes to the length of two modules and inserted them through the module hole (Figure 3b) to create an internal frame. The four pipes were tied from the back of the modules and hang from the ceiling with a thread. Everything was done by hand and the structure was very light and easy to handle. Figure 3c shows a detail of modules' side where both curved and straight creasing lines are visible decreasing the wrinkles.

The main results can be summarized as following. First, that while the Origami simulator predicted several areas of stress in the curve-creased modules, physical prototyping highlighted the tendency of corrugated cardboard to release those stresses through wrinkles or unwanted creases mainly along the sheets' corrugation channels. The strain or material deformation is evident in the unwanted creases seen, for instance, in Figure 2-a. This behavior is due to the anisotropic condition of corrugated cardboard: the material is composed channels in one direction in between two faces or liners. The template design was imposed on the cardboard sheets and did not consider the structural directionality of the flutes causing warping in some places. Accounting this material characteristic in the template design phase can improve curve-creased folding structures with cardboard. Second, although some template lines did match cardboard structure, some of them still produced unwanted creases probably due to cardboard stiffness. Thus, to help ease the folding process and prevent unwanted folds or wrinkles in the assemblies, one can add two types of extra folding lines: a) supplementary folding lines; and b) stress-releasing fold lines.

The supplementary folding lines are shown in light blue lines in the template column in Table 2 (single pass of the creasing tool) and are mainly put in place to help ease the folding process, making the fabrication of the modules not difficult. The stress-releasing fold lines are shown in hard blue lines in the template column in Table 2 (two passes of the creasing tool) and are put in place to design the strain or deformation, thus helping cardboard into the desired curved-creased assembly. In other words, with the stress-releasing lines one can guide the deformation of the material through fold lines, programming this deformation as part of the design and fabrication. The stress-releasing lines can also be part of the material aesthetic expression of curve-creased cardboard folding (see these details in Figure 3-b and 3-c). Note that this behavior is specific to cardboard, which is thick and stiff, unlike paper, which is more easily folded without exhibiting strain.

CONCLUSION

This study set out to experiment with curved-creased Origami techniques to design and fabricate complex three-dimensional forms made from corrugated cardboard sheets. Corrugated cardboard is an environmentally friendly material made from natural resources and is highly recyclable; however, it's anisotropic material property and particular sandwich type-design makes it challenging for curved creasing folding techniques. The study included qualitative (digital modeling and simulation) and experimental (digital and physical prototyping and testing) research methods. The results of the prototyping and experimentation confirmed the challenges of dealing with the anisotropic behavior of corrugated cardboard in the design of the curve-creased folding pattern. We therefore proposed using two types of creasing lines that are not typically present in curve creased design in other materials: a) supplementary folding lines; and b) stress-releasing lines. These lines helped researchers to program cardboard behavior when template does not match cardboard flutes direction and added a positively aesthetic appeal to the folds.

One limitation of this study was that we only tested the assembly of one module design, however, the use of the supplementary folding lines and stress-releasing lines might also be applicable to other cardboard-crease folding assemblies. The study findings will be of interest of architectural designers aiming at creating lightweight spatial structures with low-cardboard materials such as corrugated cardboard. Future studies will explore template patterns that follow cardboard flutes direction as well as other application scenarios of the curved-creased cardboard technique such as larger spatial structures, enclosures, and ceilings as suggested in Figure 4 below. Despite its exploratory nature, this study offers some insight into the potentials and limitations of curve-creased cardboard architectures, expanding the design language of cardboard as a building material.

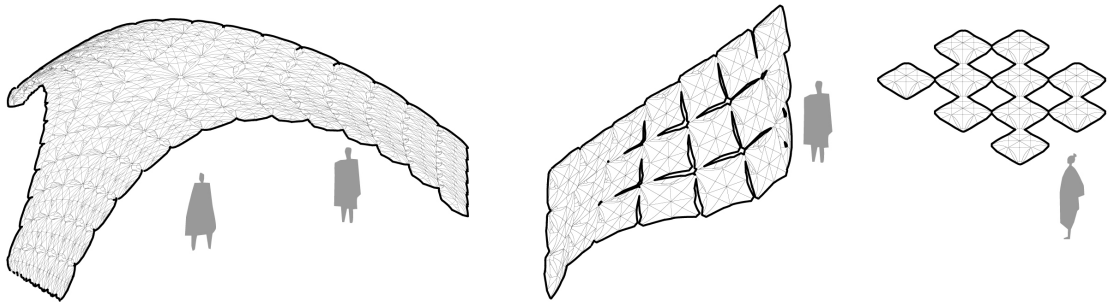


Figure 4: Proposed spatial structures. Source: (Authors 2024)

ACKNOWLEDGEMENTS

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ENDNOTES

1 See simulator at https://origamisimulator.org/
2 Other SVG import settings available by request.
3 More information on the cardboard type at https://www.uline.com/Product/Detail/S-3587

Augmented Reality Driven Design and Fabrication of Shading Devices

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ABSTRACT: The issue of sun exposure in urban settings in relation to placemaking is being studied by city planners and architects. Placemaking, which is both a physical and psychological concept, takes into account the severity of outdoor conditions and how people perceive what is considered normal, as these factors can affect the usage of space. However, many urban spaces still need to be equipped to handle increasing temperatures and broader placemaking needs. This paper proposes an augmented reality-driven design process that utilizes mobile devices to generate shading structures accessible to non-experts. The generative algorithms simplify the creation of design iterations and use material simulation to develop shading devices based on looped surfaces. Moreover, incorporating AR into the fabrication process simplifies construction, making it more accessible and engaging for a diverse range of participants. The research presents an accessible design approach and a fabrication methodology suitable for non-construction professionals, which can be applied in various contexts to provide shade with minimal infrastructural demands. This study contributes to the expanding discourse on the use of AR in architectural design and fabrication, with a particular focus on shading. The envisaged accessible and engaging approach will promote wider community involvement in shaping urban spaces, offering viable solutions to rising temperatures in urban environments.

KEYWORDS: Augmented Reality in Construction, Participatory Design, Augmented Reality for Design, Digital Fabrication, Shading Devices

1.0 INTRODUCTION

Urban public parks play an increasingly crucial role in providing recreational activities for diverse urban communities. The design of these spaces needs to accommodate social activities and the experience of urban ecosystems, particularly in subtropical cities like San Antonio, where mitigating the impact of direct sun exposure is critical. Predictions suggest that by 2050, San Antonio will endure five months of temperatures exceeding 100.4°F (38°C), amplifying the existing severity of its climate (Boice and Garza 2021). Recognizing these potential environmental challenges, the city council has called for action (Office of Sustainability 2019). San Antonio studies emphasize the criticality of shade in improving thermal comfort in open-air spaces (Patel, 2015), and recent case studies on shading structures underscore the need to integrate climate comfort into design considerations using computational tools (Ameijde et al., 2022).

In the context of architectural production, digital design and fabrication can significantly influence the planning and creation of shading structures in urban parks. By harnessing computational design tools and adopting user-focused fabrication techniques, architects can make well-informed decisions to produce custom-made shading devices. Parametric design in architecture presents a unique opportunity to create numerous iterations of a single concept without requiring extensive human input (Figure 4-5). This approach can significantly accelerate the design process by streamlining the drafting and management of design assets (Monedero 2000). A reconfiguration strategy has been proposed to embed interactive behavior in a shading canopy, ensuring shadows in occupied spaces (Wood et al., 2019). However, the user does not have direct access to configure or design where and what kind of shadow is to be created.

The application of Augmented Reality (AR) – the overlay of digital information onto the real world – offers numerous innovative design opportunities. In architectural design and fabrication, AR finds utility in visualizing plans, monitoring progress, aiding workers, revealing hidden utilities, allowing remote experts to guide on-site personnel in real-time, verifying code compliance of assembled structures, and enhancing the efficiency of construction equipment (Nassereddine, Veeramani, and Hanna 2022; Chi, Kang, and Wang 2013). Additionally, AR has been utilized in crafting complex architectural assemblies (Hahm 2019; Jahn, Newnham, and Berg 2022). However, its application remains limited, primarily due to unfamiliarity with the technology, environmental challenges at construction sites (Kassis et al. 2022), or implementation costs (Ramsey & Hongtao 2022), while industry trends suggest a growing adoption of AR (Noghabaei et al. 2020). The benefits of collaborative AR for interior design have been presented as early as 1995 (Ahlers et al. 1995). An extended reality collaborative design review process has been trialed with promising results, augmenting a physical mockup or an existing environment in situ. This approach has demonstrated its potential to enhance inclusivity and active participation during design and planning processes (Gillespie et al. 2021).

Nevertheless, when it comes to non-experts' engagement in the design and fabrication process via AR technologies, it remains under-researched or not extensively explored. Additionally, the development of AR tools

for user-guided on-site design and production of shading devices, and the use of the material behavior of bendable materials in this context, present unique contributions to this body of research.

In response to these challenges, a case study was conducted at Legacy Park in Downtown San Antonio, an urban park grappling with heat-related issues. The choice of location was influenced by past design decisions that minimized shade, leading to lower-than-anticipated visitor engagement during spring and summer. The site's diverse programmatic demands require a response to various conditions. The client intends to install metal wires over the park, allowing for the flexible positioning of shading devices.



Figure 1: Placement of a shadow area via the AR application. Source: (Author 2024)

2.0 METHODS

This research introduces a method of creating user-defined shadow areas on mobile handheld devices via an on-site AR interface (Figure 1). Based on the identified shadows, 3D geometries are projected onto the planned wires above the site. These geometries are further refined through material simulations to define shadow density accurately. An AR fabrication tool has been developed to leverage the properties of bendable materials and enable on-site production of shading devices by participants with minimal construction knowledge. This tool provides detailed fabrication instructions for bending and securing a polycarbonate film into the desired shape. The proposed methods are designed to heighten engagement and inclusion in shade creation, deploying human-centric AR tools during the design and fabrication stages. This approach was validated through the design and construction of a full-scale prototype.

This research followed the case study approach and was conducted in an academic setup at the University of Texas at San Antonio in collaboration with Weston Urban and Dunaway. The design team comprised a Building Design Studio with fourteen students at the University of Texas at San Antonio from January 18th to May 4th, 2022. This study involved implementing and testing climate simulations, parametric design, and AR-assisted fabrication.

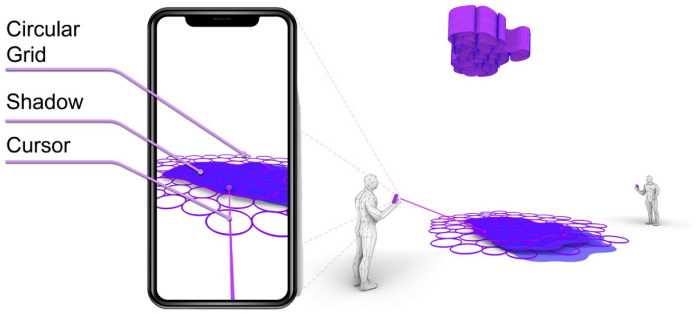


Figure 2: Mobile app concept diagram. Source: (Author 2024)

2.1. Design Methods

An augmented reality tool was developed to assist with on-site positioning and evaluation of shading devices using Fologram in Grasshopper for Rhino 3D (refer to Figure 2). This tool enables users to specify the desired times for shadow by pointing a cursor on the ground, adding a circle to the shading with just a click on the mobile device screen, and projecting the shading device up into the air. The projected shadow is then visualized at fifteen-minute intervals, distinguished by various shades of blue in the application.

The AR tool's geometric system is based on a bendable material, polycarbonate, which is easy to manipulate and weld by non-experts. The placement grid is circular in response to the material system of the bendable sheet. The size of these circles adjusts based on the number of user-proposed shadows at different locations, with more

proposals resulting in larger circles. This feature provides users with insights into previous shading proposals, enabling them to either reinforce existing proposals or suggest other shadow locations.
This dynamic circular grid was realized using a particle-spring simulation, specifically Kangaroo for Grasshopper, in which the circle's radius reflects the frequency of user-placed points at the location. A threshold restricts the number and size of the circles to maintain a manageable visual representation.

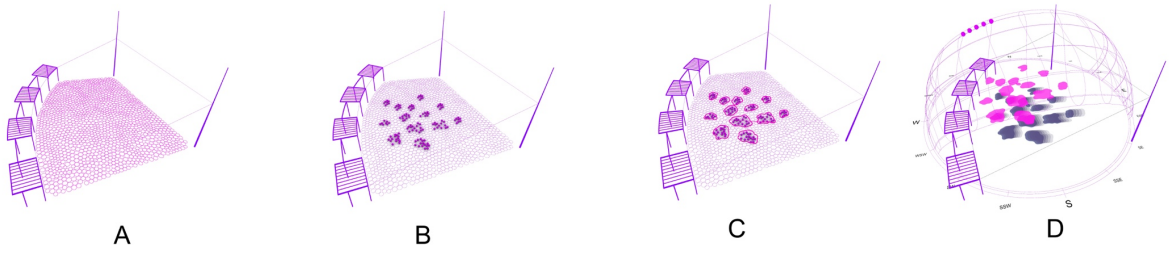


Figure 3: The site constraints: the possible space (A), the adapted grid (B) for the placement of shading devices (C), and a layout option with shading devices placed between the wires with shadow from 15:00 - 16:00 on the 15th of July (D). Source: (Author 2024)

"To meet the site's specific requirements, configured constraints for the application. These constraints included limiting possible locations for shading devices to align with a planned wire layout, which was dictated by two existing posts and a pergola (Figure 3)."The tool prompts users to apply shadows to the site by marking points and generating a metaball polyline encircling these points (also shown in Figure 3). This metaball is then transformed into a mesh and projected to the wire height, roughly between four and five meters (approximately 14 to 16 feet). This mesh is further translated into a pattern of bending and aligning curves that mirror the behavior of the fabrication material. Rhino 7 software was used to generate these patterns, combined with the Grasshopper and Kangaroo 2 plugins. The boundary is then offset inwards and programmed to expand, provided it does not self-collide, thereby simulating the bending behavior of the polycarbonate. Users have the flexibility to select from different pattern densities by altering the total length of the individual curve. The output is a dense pattern that can provide the desired shadow. Generated patterns are user-controllable and can be modified by adjusting the input parameters, such as the offset distance and the line growth rate.

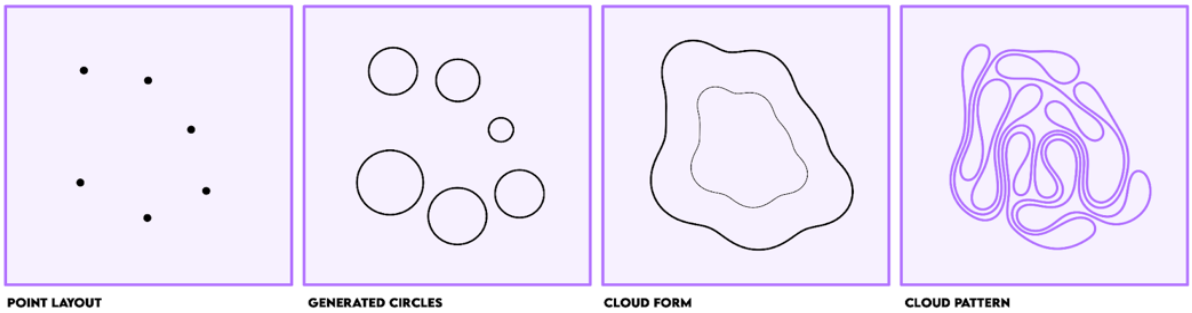


Figure 4: The processes of pattern generation for the ribbon forms, Source: (Author 2024)

2.2. Shadow Analysis

A *Universal Thermal Climate Index* (UTCI) analysis was conducted to create a thermal comfort map of the site, allowing a predictive analysis of the impact of the shading devices. The UTCI calculation considers four main variables: dry bulb temperature, mean radiant temperature, relative humidity, and wind speed. Metrics of human comfort are estimated using universal data on human adaptive behavior, and other essential factors, such as age, height, and weight, are derived from population averages (Mackey et al. 2017). The relevant buildings, site vegetation, and shading devices were input as meshes into the Ladybug plugin in Grasshopper (Roudsari et al. 2013). A mesh was laid over the site with 2009 measuring points (Figure 5). For the measured period on July 15th from 11:00 AM to 2:00 PM, the site had an average air temperature of 32.2 °C and a mean radiant temperature of 54.6 °C based on the weather data from EnergyPlus for San Antonio. The measured UTCI temperatures were averaged and translated into a thermal comfort heat map (Figure 5).

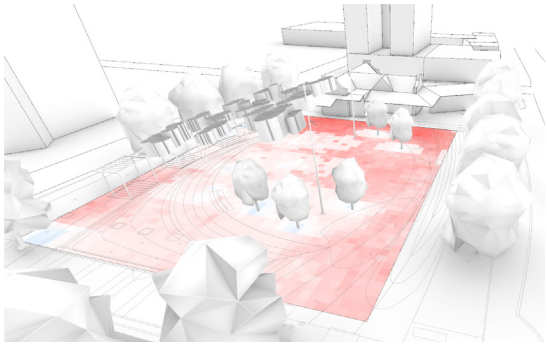


Figure 5: A perspective showing the elevation of the shading devices above the ground and the mesh colored based on the heatmap. Source: (Author 2024)

2.2. AR assisted prototyping

The project's 3D forms were actualized by bending a continuous, thin film to conform to the generated patterns and forming joints at intersections of the film. These polycarbonate films are flexible, UV-resistant, 0.02 inches (0.5 mm) thick, and 48 inches (1219 mm) high. Moreover, the thermoplastic characteristics of the polycarbonate permitted it to be shaped without fracturing or needing a mold.

The Fologram app was used to establish an Augmented Reality (AR) aided construction environment to support the construction of the prototypes. The AR model's primary function was to render the design visible in real-time as it was assembled and to offer a guide for bending the polycarbonate. This ensured that the prototype closely mirrored the intended design. Additionally, the digital 3D model can be loaded onto AR-compatible devices, enabling it to be visualized during the construction process.

Construction tasks were divided into supervisory and building roles. The supervisor monitored the overall model using an iPad handheld device, ensuring the prototype retained its correct form. Additionally, one individual donned an AR headset (Microsoft HoloLens2) to facilitate construction (see Figure 6).

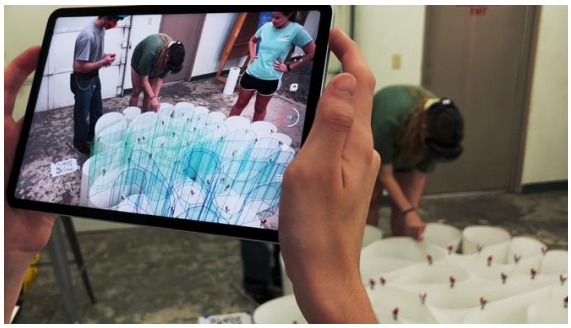


Figure 6: 1:1 prototype assembly process. Supervisors on the left are comparing the built form to the AR model and inspecting it for inconsistencies. Source: (Author 2024)

The builders, equipped with Microsoft HoloLens, guided the clamping and welding of the polycarbonate at a more local scale. A slider interface was implemented to create a more interactive process that allows the builder to alter the percentage of the AR model shown at a time (Figure 7). With this, the builders could visualize prototype segments without the overlay obstructing their vision.

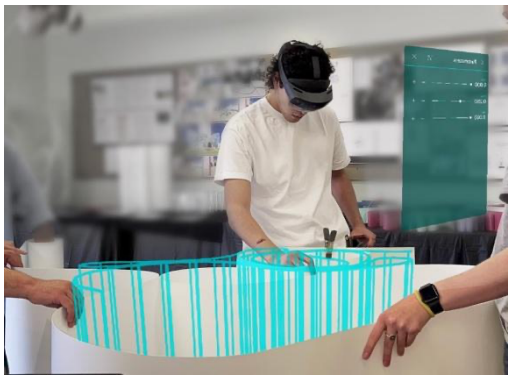


Figure 7: The 1:1 augmented prototype assembly process shows the geometrical overlay and the user interface. Source: (Author 2024)

Small-scale prototypes were created at different sizes to test joint methods and bending behavior. Various heat-based tools were used for the smaller prototypes, including hot air guns, impulse heat sealers, soldering irons, and welding guns. The tested welded joints include punctured fusion welds, continuous fusion welds, circular fusion welds, and W-shaped fusion welds (as shown in Figure 8). From the preliminary tests, intermittent W-shaped fusion welds were determined to be the most robust option. For the 1:1 prototype, W-shaped fusion welds were used to join polycarbonate film at five evenly spaced points along the vertical axis. Each joint connected a maximum of two layers. The prototype joints were roughly aligned along a central axis to strengthen it in the direction of the cables and to allow prototypes to be compressed for storage. On-site, a two-story truss system was constructed, and the 1:1 prototype was suspended in the air for one week to test the feasibility of the joints. Several cameras were used to monitor the prototype during this period, and the effects of the prototype on on-site conditions were also monitored.



Figure 8: The W-shaped fusion welding tool and its application for the 1:1 prototype. Source: (Author 2024)

3.0 RESULTS AND REFLECTIONS

This research presents AR-based on-site design and fabrication processes for shading devices based on computational design and shadow simulation guided by human decisions. Each step of the design process informs the following process. Collecting the necessary shadow analysis generated a design that efficiently responds to reducing direct sun exposure and improving thermal comfort.

3.1. AR-based design

The AR design tool enabled non-experts to place shading areas as desired within the existing circular grid. Figure 9 shows a user during the process of using the cursor to select the shading areas while being able to get a view of the shading devices projected along the sun vector.

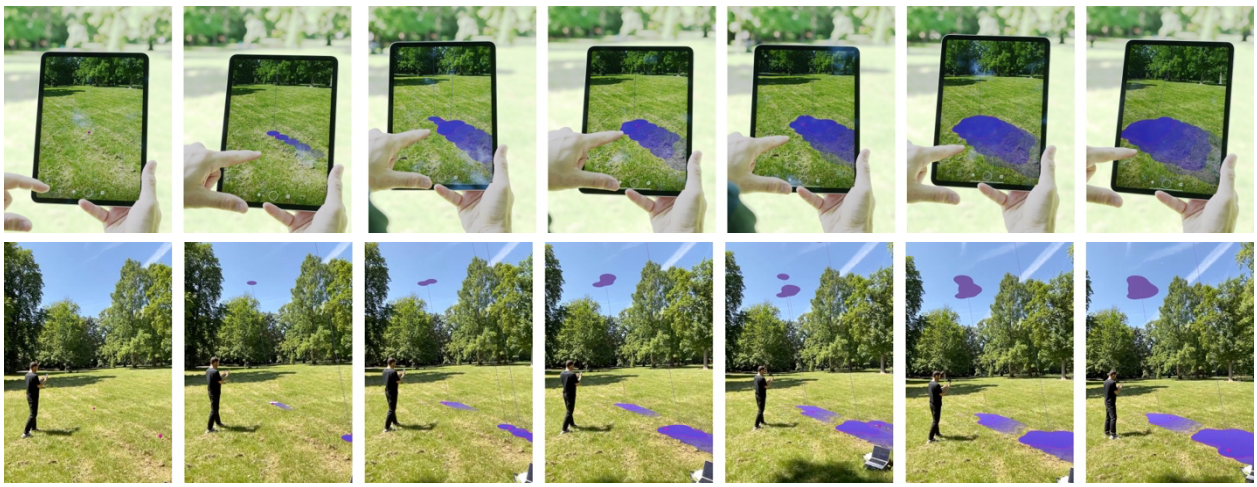


Figure 9: Stills from video capture during the placement of shaded areas via the AR application. The top row shows the placement on an iPad, and the bottom row shows the placement from a second device. Source: (Author 2024)

The layout and pattern generation scripts streamlined the iterative phases of the design process. With it, a single designer could produce and test numerous designs within a limited time frame. Additionally, the introduction of limited randomness contributed to the final design's aesthetic, which incorporated both material properties and functionality. A final design was achieved through a material-based design system that leveraged the properties of polycarbonate. In the context of shading structures, this process was used to find the pattern that maximizes shade while considering the material and fabrication constraints of the film material.

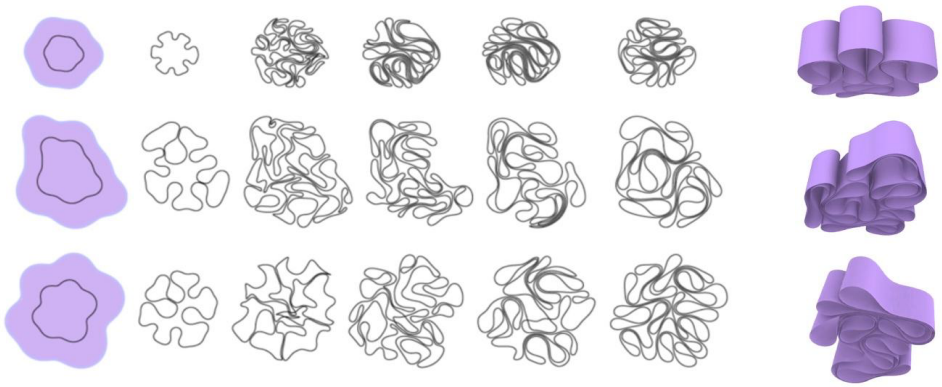


Figure 10: Examples of the script generating patterns of differing complexities and densities Source: (Author 2024)

3.2. Sun hours

Monochromatic shade models were constructed to calculate the concentration and total area of the shade cast by the structure (Figure 11). The location and area of the smallest and largest possible shadows cast were also determined. Control tests were run using solid blocks of equal dimensions for both models. Outputs were converted into percentages and used to gauge the effectiveness of the given forms.

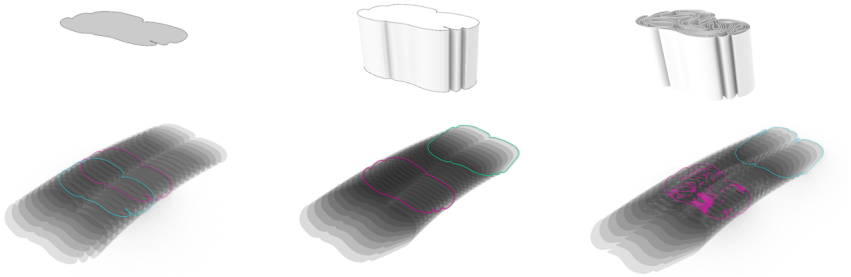


Figure 11: Shadow analysis on July 21st from 11:00 AM to 3:00 PM for a flat surface without perforation (left), a solid geometry (middle), and the generated form (right). Source: (Author 2024)

A direct sun hour analysis was implemented, focusing on the immediate area surrounding a single, suspended structure (Figure 12). Using meteorological data from San Antonio, the hours of solar exposure on July 21st from 11:00 AM to 3:00 PM were calculated in 5-minute increments.

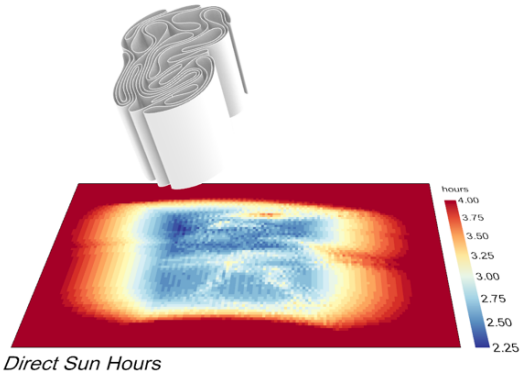


Figure 12: Direct sun hour analysis on July 21st from 11:00 AM to 3:00 PM in 5-minute increments. Source: (Author 2024)

Our measurements recorded both increases in shadow area and reductions in hours of direct sun exposure. As depicted in Figure 11, the pattern generates a maximum shadow of 5.07 m² (cyan) and a minimum shadow of 2.8 m² (pink). In contrast, the solid block generates a maximum shadow of 5.51 m², while the flat surface generates a maximum shadow of 3.38 m². Solar radiation analysis, shown in Figure 10, indicates that only minimal spots remain exposed to sunlight. The total area experiencing reduced solar exposure by more than an hour was 7.5 m², and the

overall area observed to have reduced solar exposure amounted to 16 m². Compared to the 3.4 m2 footprint of the polycarbonate form, the maximum area of solar protection is 4.7 times larger.

While the perforations impact the shadow area generated, the combination of orientation and depth in the design made this effect minimal. This is vividly demonstrated by the shading structure's smallest shadow; even though perforation allows some light penetration, the angle ensures this happens during times of the day with less cooling demand and in quantities too minimal to undermine its utility. The layout proposed in the UTCI analysis reduced the average temperature by 3-4° Celsius. The average perceived temperature in the analyzed area transitioned from 36.34 °C without intervention to 35.78 °C with the implementation of shading devices. With the proposed twelve geometries, approximately 50 percent of the site's main lawn underwent temperature reductions significant enough to enhance thermal comfort. These results align with the temperature reductions offered by deciduous trees, as shown in Figure 13. Such results confirm the feasibility of larger-scale applications of the approach for AR-assisted shading design.

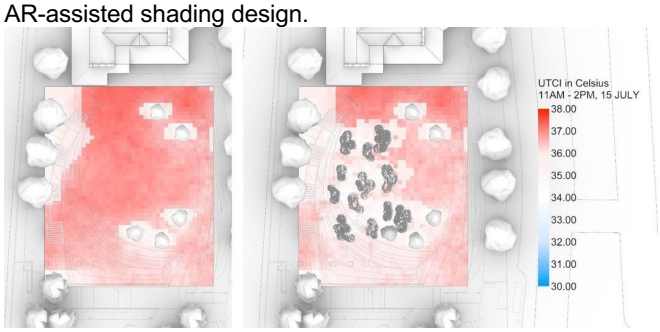


Figure 13: The UTCI heatmap for the site before intervention (left), including the shading devices (right). Source: (Author 2024)

3.3. Prototyping

The results of the 1:1 prototype test underscored the concept's potential for creating comfortable pockets of shade. The entire construction process, greatly simplified by the use of AR-assisted design, was completed in less than a day by a team of just four builders. The AR technology was an accessible blueprint, providing workers with clear assembly instructions. The segmentation of the AR model streamlined the information delivery to the builders, enhancing efficiency. Among the two devices used, the HoloLens goggles proved superior to the iPads, enabling workers to visualize the model while actively building. The flexibility of this phase permitted modifications to the prototype during assembly. Builders could suggest changes to the pattern or the size of the curves within the constraints of ensuring future connections remain secure and consistent with the pre-established outline. The AR model could be swiftly updated to reflect any alterations and used to set a new endpoint if necessary. During construction, producing W-shaped fusion welds was rapid and cost-effective. While polycarbonate was used in this prototype, other more sustainable, eco-friendly materials could be used in future iterations. For instance, bioplastics or recycled plastics could be considered, reducing the environmental footprint while maintaining the requisite flexibility and strength. Material selection should also consider potential outgassing or chemical release during welding, favoring materials that minimize these risks.

While the prototype's overall stability was satisfactory, it was noted that a single joint failure occurred along the exterior of the prototype. The timing and cause of this break are unclear, possibly due to mishandling during disassembly; however, this incident highlights the need for more robust, reinforced connections in future prototypes. On-site monitoring confirmed the prototype's effectiveness in providing shade during the afternoon, particularly when the sunlight was directly overhead – the most crucial time for shade provision (Figure 14). Even when sunlight struck the prototype at an angle, the cast shadows were large enough to ensure thermal comfort. The prototype balanced its shading function with preserving views of the sky, avoiding the monolithic appearance of a solid shading surface, a testament to the potential of this approach.

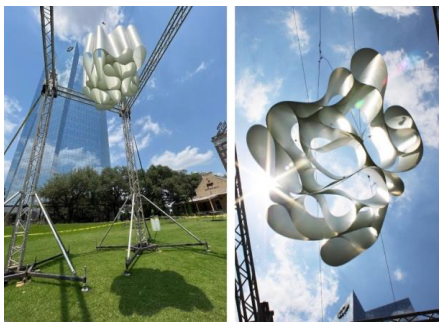


Figure 14: The 1:1 prototype was installed with a provisional truss structure on site, with its shadow cast on the lawn (left) and the view through the perforated shading device (right). Source: (Author 2024)

CONCLUSION

The research presents a comprehensive approach to mitigating direct sun exposure by employing computational and on-site participatory design, shadow analysis, and digitally augmented fabrication, aided by augmented reality (AR). The integrated design process caters to diverse programmatic needs and successfully improves thermal

comfort while addressing essential placemaking necessities. Tests confirm that the innovative structure effectively generates perforated shade, striking a balance between sun protection and unobstructed views.

The on-site design tools provide a comprehensive understanding of each shading intervention at the site scale, allowing users to focus on designing shadows rather than the shading device itself. Tailored computational design tools were developed explicitly for bending-active polycarbonate structures. Combined with the AR-assisted fabrication process, this offers a cost-effective solution that empowers many users to design and construct shading structures.

This research builds upon existing studies that strive to harness AR for design and fabrication, integrating material behavior through computational tools. The workflow developed can be applied to a multitude of projects across diverse sites, utilizing 3D data of the surroundings to generate site-specific shading solutions. The simulation of material behavior within these computational analyses merits further exploration, with the potential to optimize the creation of perforated shading devices. Moreover, incorporating AR into earlier stages of the design process promises to democratize design and enable on-site construction by individuals without professional training.

This case study enriches the repertoire of available methods and tools for creating shade in urban parks experiencing extreme heat, such as those in San Antonio. The approach empowers a participatory design process and simplifies construction, making it accessible even to those without formal training. Overall, the project demonstrates how accessible, technologically supported methods can improve thermal comfort in public spaces, contributing to more resilient urban landscapes.

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Breaking the Renovation Cycle: Learning from Architectures of the Past for Low-Metabolism Building Design Today

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ABSTRACT: The paper develops new knowledge of patterns of building material consumption in renovation and adaptation cycles, to design new buildings to have a lower future material use in their use-stage. By comparing component lifespans and environmental impacts of material uses in the life of three cases in Copenhagen, Denmark, certain architectural characteristics were found to influence the levels of material use and sequences of change. The cases were: a preindustrial case (*1755) with multiple transformations of use, an industrialised case (*1972) and a control case (*1958) from right before industrialised building practices intensified in Denmark. Change patterns, material uses, and environmental impacts differed significantly across the three cases from preindustrial to industrialised building cultures. In the qualitative interpretation of the quantified material changes, the paper challenged Duffy and Brand's models of "Shearing Layers of Change" and Design-for-Disassembly frameworks with a design principle focused on the relationships of component types and their *"hierarchy of alterability".* This principle could be used in the design of new buildings and in transformation projects to meet shifting user needs while lowering the use-stage consumption of materials over a period of 200+years of use and adaptation.

KEYWORDS: Hierarchy of alterability, LCA use-stage, material flow, lifespans, adaptability, lasting architecture.

INTRODUCTION

In Denmark, reuse covers 6,5% of current needs for building materials, and up to 18-25% if every demolished square meter and gram of demolition debris was reused despite toxins (R. Andersen 2023). This highlights that Circular Economy strategies of reuse need complementary strategies to tackle the construction industry's material consumption and environmental impacts. Renovations of buildings and their components occur many times in their relatively long use-stages. In Denmark, the renovation industry is about 65% larger than the new constructions-industry (measured by production value) primarily due to use-stage refurbishments and replacements of the building envelopes, HVAC/plumbing, and interior fittings (Rasmussen and Birgisdottir 2015). Considering the size of the renovation sector, the consumption of building materials is not only costly but also with large environmental impacts (Rasmussen and Birgisdottir 2015; Duffy 1990). Nonetheless, Danish Building Code currently excludes the module "B5: Refurbishment" from Life Cycle Assessment requirements (LCA) and uses a building lifespan of just 50 years whereas buildings in Denmark are predicted to last an average of 200 years (Aagaard et al. 2013). Further, were the LCA's 50 years calculation period extended to 80 years, the environmental impact from replacements of building components would triple (Zimmermann et al. 2020). While overlooked in policy, practice, and research, the material use in the use-stage of buildings clearly holds a potential as a field of study to lower the industry's environmental impacts (Pomponi and Moncaster 2016; Bowyer et al. 2022). To explore this potential, historiographies of change in buildings from different building cultures could yield new insights. Existing studies have shown:

- How load-bearing structures can be designed to adapt to future uses, yet without a focus on the most frequently added/removed building components in renovations. (Till and Schneider 2005; Wilkinson 2018; Geraedts 2016)
- Technical lifespan properties of building components to withstand deterioration, yet not with a focus on reduced material use in renovation/adaptation in new-builds. (Ejstrup 2019; Loonen et al. 2013; Aagaard et al. 2013)
- Economics of marginal utility (Stigler 1972) and the Rent-Gap Theory (Smith 1987) to theorise when a product/component/existing building meets demands or cannot fully capitalise on current market potentials.
- Aesthetic/architectural qualities, mainly in low-rise preindustrial buildings, yet not systematic studies of characteristics that impact practices of material use in multistorey, urban buildings (Hassler 2020; Ventzel Riis et al. 2021; Eybye 2016; Bak-Andersen 2020, Andersen 2015).

There is a research gap on the relationship between architectural characteristics and material consumption patterns in buildings' use-stage, and on studies that combine quantitative material flow analyses with qualitative assessments of architectural characteristics. Further, material flows and component lifespans have, to our knowledge, not been studied in the comparison of multistorey, urban preindustrial and fully industrialised buildings. The paper focuses on both of these aspects. To limit the scope, the study foregrounds the increasing scarcity of natural resources from building material consumption in the use-stage (Seifi 2021) and does not asses operational energy, comfort standards, or user expectations which have been studied widely (Azari and Abbasabadi 2018).

1.0 RESEARCH QUESTION

How do patterns of change, material uses, and environmental impacts of use-stages in preindustrial and industrialised buildings compare, and how may this comparison inform design decisions to lower the consumption of building materials in future use-stages in new-builds and transformation projects?

2.0 THEORY

The environmental impacts from building material uses in renovation and adaptation cycles are commonly quantified via LCAs. Here, both operational energy and embodied energy (EE) are calculated with the metric of kg CO_2-eq/m2 in a 50-year calculation period, using pre-tabulated component lifespans (Rasmussen and Birgisdottir 2015). Since this study assesses EE of materials only with the use of actual component lifespans from the cases instead of generic data, the term "metabolism" is used, adapted from the theory of "Metabolism of the Anthropocene" (Brunner and Rechberger 2017). The metric remains kg CO_2-eq. of material use per m^2 per year from renovations and adaptations, documented in the period of archival material availability in the use-stage of each case.

Patterns of change are qualitatively compared among the cases with two theoretical models of the sequences and categories of change: Francis Duffy grouped building components with similar lifespans into four "layers": "Shell", 50 years (foundations, walls, roofs, structure), "Services", 15 years (HVAC, plumbing), "Scenery", 5-7 years (partitions, interior fittings, furnishings, surfaces), and "Sets", a day (moveable furniture) (Duffy 1990). Stewart Brand named this theory "The Shearing Layers of Change", added a permanent "Site", and split Duffy's Shell in two: "Skin", 20+ years (building envelope), and "Structure", 30-300 years. Finally, Brand renamed Scenery into "Space Plan" and Sets into "Stuff" (Brand 1995). When referring to any of these layers, the first letter is capitalised, e.g. Shell. To represent the received, silent knowledge of practicing architects, renowned architect and writer Rafael Moneo's hypothesis of what makes buildings last is used as an additional qualitative analytical lens. Moneo's theory springs from a case study analysis of the 800 year adaptive reuse history of the Mosque of Cordoba in his essay, "Life of Buildings: The Mosque of Cordoba" (Moneo 2017). Moneo used the mosque as a paradigmatic case (Flyvbjerg 2006) of *robustness* which was achieved by *"its formal structure, and in the principles upon which this structure depends"* (Moneo 2017, 2). The architecture could withstand alteration because it was *"defined with enough clarity (…) to be always present"* and used *"already-used elements"* from various traditions to make architectural principles easy to recognise, see value in, and keep across time (Moneo 2017, 5). In this theory, robustness or longevity is achieved when (architectural) principle and structural logic fully overlap and are visibly present in every building element, communicated to users over time through the use of well-known building elements, syntaxes, and materials, echoing Alberti's and Vitruvius' writings (Alberti 1991; Vitruvius 1960). While not explicitly used for the analysis in this paper, the article also builds on a lifespan model from engineering by BUILD (Department of the Built Environment, Aalborg University, Denmark) to categorise different qualities that impact a component's lifespan: technical (physical durability), functional (meeting programmatic needs), economic (operations viability), and aesthetic (meeting owner/users "aesthetic standard") (Aagaard et al. 2013).

3.0 METHODS AND SELECTION OF CASES

The paper uses mixed-mode research methods (Aksamilja 2021). In summary, three case studies are chosen, data is gathered through archival research, material changes are mapped, and the metabolism of renovations and adaptations of each case is quantified. Patterns and frequencies of change, component lifespans, and material uses are comparatively analysed across cases with Duffy and Brand's models of change and Moneo's example of the received knowledge of practicing architects on the dependency of a structural logic on architectural principles.

For the case selection, the paper uses an "information-oriented" strategy to choose three cases based on the expectation that they are rich in information content (Flyvbjerg 2006). One case is selected to represent a preindustrial, premodern building culture, another case to represent an industrialised building culture, and a preindustrial control case is added for a sensitivity analysis. All three cases are chosen to come as close to "critical cases" as possible for deductions of the type *"If this is (not) valid for this case, then it applies to all (no) cases"* (Flyvbjerg 2006, 230). To minimise selection bias, cases are selected on their independent rather than dependent variable (King, Keohane, and Verba 2021), as the main criterion of the three cases – building age – is independent from the dependent variables of metabolism and component lifespans (to the best of authors' knowledge). To select the preindustrial case, 2000+ buildings in Denmark are screened from the office portfolio of preservation and adaptive reuse projects of RØNNOW LETH & GORI, host company of the industrial Ph.D.-project. The inventories of physical and digital case folders enabled a screening with the following selection criteria: 1) *200+ year old (to gather knowledge to design new-builds in a 200+ year perspective),* 2) *Unclassified status for public disclosure,* 3) *Multistorey, premodern, preindustrial (research gap for multistorey, premodern, preindustrial buildings),* 4) *Urban, in Copenhagen Municipality (urban buildings have a longer use-stage and thus greater material use in renovation/adaptation (R. Andersen 2023)),* 5) *Rich transformation history (with the assumption that transformations entail significant spatial reorganisation and material use. If the preindustrial case's material use is low compared to the industrialised case with no transformations, the more robust will findings of a lower preindustrial metabolism be),* 6) *Period of data availability.* 13 cases matched all criteria, had 2+ adaptive reuses, and were at least 250+ years old. Søkvæsthuset by J.C. Conradi, 1755, is chosen, due to long data availability (1755-2006) and six whole-building transformations of use. To overcome the difficulty of comparing two primary cases of different locations, weathering conditions, design quality levels, maintenance/repair cycles, and programmes, the following criteria were used to choose both the industrialised primary case and the preindustrial control case: 1) *Built right before/after the Montage Circular (1960) which rapidly industrialised Danish building culture,* 2) *Built by the same architect with a comparable level of design quality*, 3) *Built in direct proximity to have similar weather conditions and other localised impacts,* 4) *Administered by the same housing association to have similar operations management,* 5) *Comparable programme*, 6) *Built by a renowned architect to ensure high design quality*. The industrialised case Tingbjerg Dormitory, designed by renowned architect Steen Eiler Rasmussen and constructed in 1972 (with data availability from 1972-2012), was selected as the industrialised primary case. This case matched all the criteria and faced a building constructed right before 1960 in the same street, by the same architect, same housing administrator, and with a comparable programme, namely the Tingbjerg Family Housing constructed in 1958 (with data availability from 1958-2023) which was chosen as the control case of a pre-industrialised construction practice.

To limit the scope of the paper, Yin's *embedded unit* analysis of multiple cases is used (Yin 2018). Yin proposes a cross-disciplinary case study research method to analyse single or multiple cases in one or more units of analysis *embedded* within one or multiple cases, as a representative part of the whole. Representative sections of regular floor plans of each case (all 2nd floors) are chosen: Søkvæsthuset's embedded unit includes >25% of each of the four room sizes on the regular floor plan, >25% of the long façade, a primary and secondary heating source, one of two main stairwells, and the three forms of vertical loadbearing structure: outer walls, inner walls, and columns – a total of 191 m^2. Tingbjerg Family Housing's embedded unit includes one standard apartment and a stairway shared between two apartments, a total of 99 m^2. Tingbjerg Dormitory's embedded unit includes a shared kitchen and four of the ubiquitously sized and fitted dorm-rooms, a total of 157 m^2. (See Figure 1 in 4.0) Archival Research (Aksamilja 2021) is performed to assemble, organise, and analyse each case's drawings and text documents from the project archives of RØNNOW LETH & GORI, the Danish National Archives, and the Municipality of Copenhagen Building Case Records. All material relevant to the renovation/adaptation history of each case is arranged into chronological folders and drawn in a series of plan and elevation drawings in AutoCAD.

An LCA of each case's metabolism is calculated for the LCA A1-A3-phases only, since actual building component lifespans and refurbishments in the B-phases modules are documented through the archival work, and C- and D-phases are omitted because of the significant differences in reuse practices before and after 1960 (Bak-Andersen 2020) and since construction waste from demolitions accounts for just 3% of the environmental impact in contemporary practice (Rasmussen and Birgisdottir 2015). The calculated volumes (m^3) of each material added in the renovation/adaptation history of each case is converted into kg CO_2-eq. with the digital tool "The Construction Material Pyramid" (CINARK 2019), a database of EPDs, analogous to other LCA-tools. For materials not included in the database, building components with EPDs are used as substitutes. The kg CO_2-eq.-results are divided by the embedded unit-size (m^2) and by the studied time-period (years) of each case respectively.

Subsequently, patterns of change, component lifespans, and metabolisms across the three cases are compared and discussed with the theories of Brand, Duffy, and Moneo. This discussion aims to develop qualitative, empirically rigorous design knowledge and, in turn, to discuss the models of Duffy, Brand, and Moneo against the findings.

4.0 RESULTS

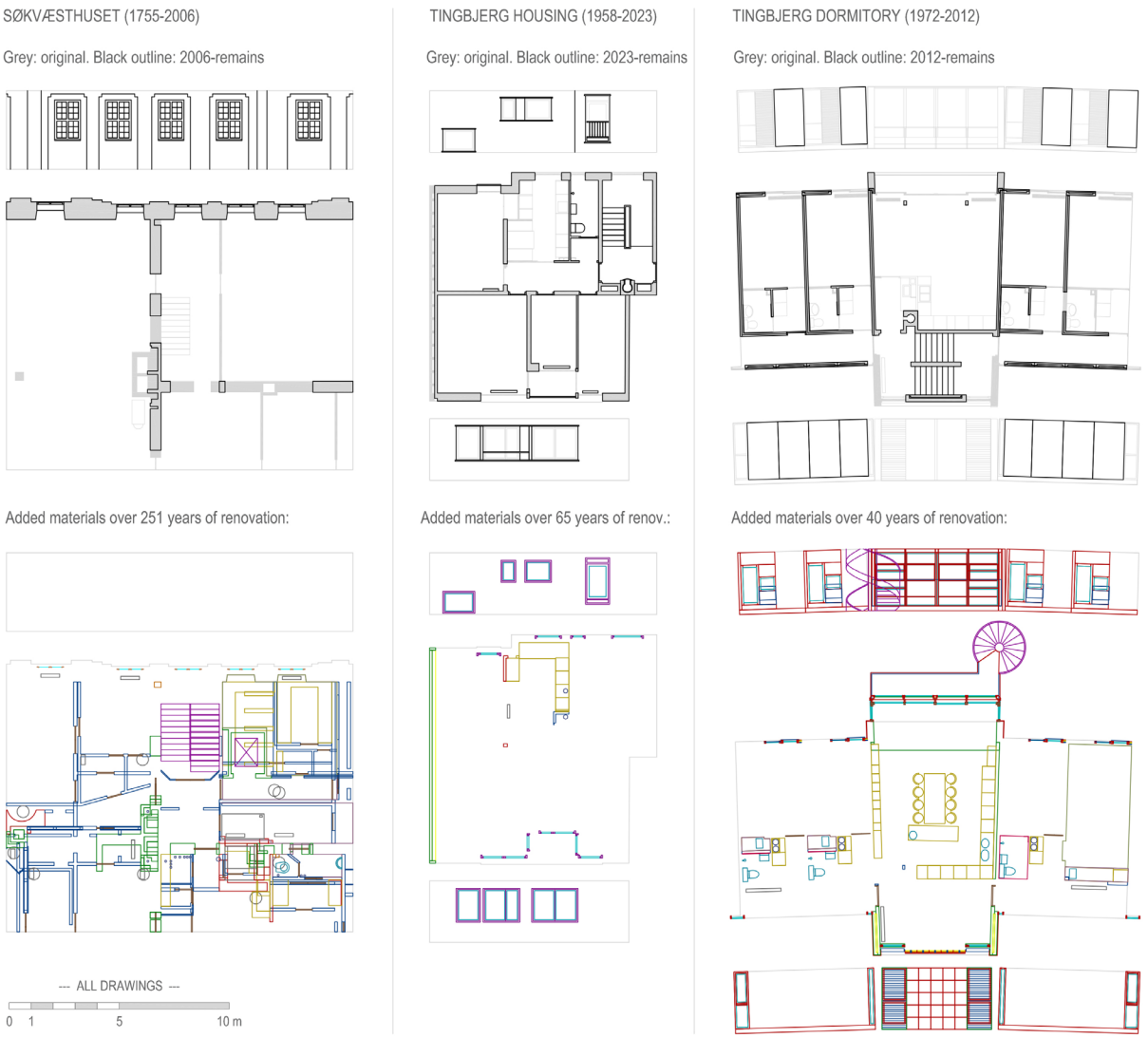


Figure 1: Metabolisms of the embedded units of the three cases, redrawn from archives. Source: (1st author 2024)

4.1. Søkvæsthuset's metabolism (1755-2006)

Søkvæsthuset's Shell was the longest lasting layer, followed by Services, and lastly Scenery, as predicted in Duffy's categorisation. This order slightly deviates from Brand's theory: Søkvæsthuset's Skin is structural and was the longest lasting layer, followed by Structure in terms of inner structural walls, Services and lastly Space Plan (/Scenery). Half of Søkvæsthuset's metabolism was concentrated around just three datapoints in the first 110 years (see Figure 2). These spikes occurred with the first two changes of use – to hospital and to barracks. The other half of the metabolism was spread out more evenly over the following 141 years and 13 datapoints. However, the partial change of function to apartment units (1870), and the introduction of bathrooms (1888), radiators (1933), and an elevator (2003), were main contributors to the overall metabolism of Søkvæsthuset.

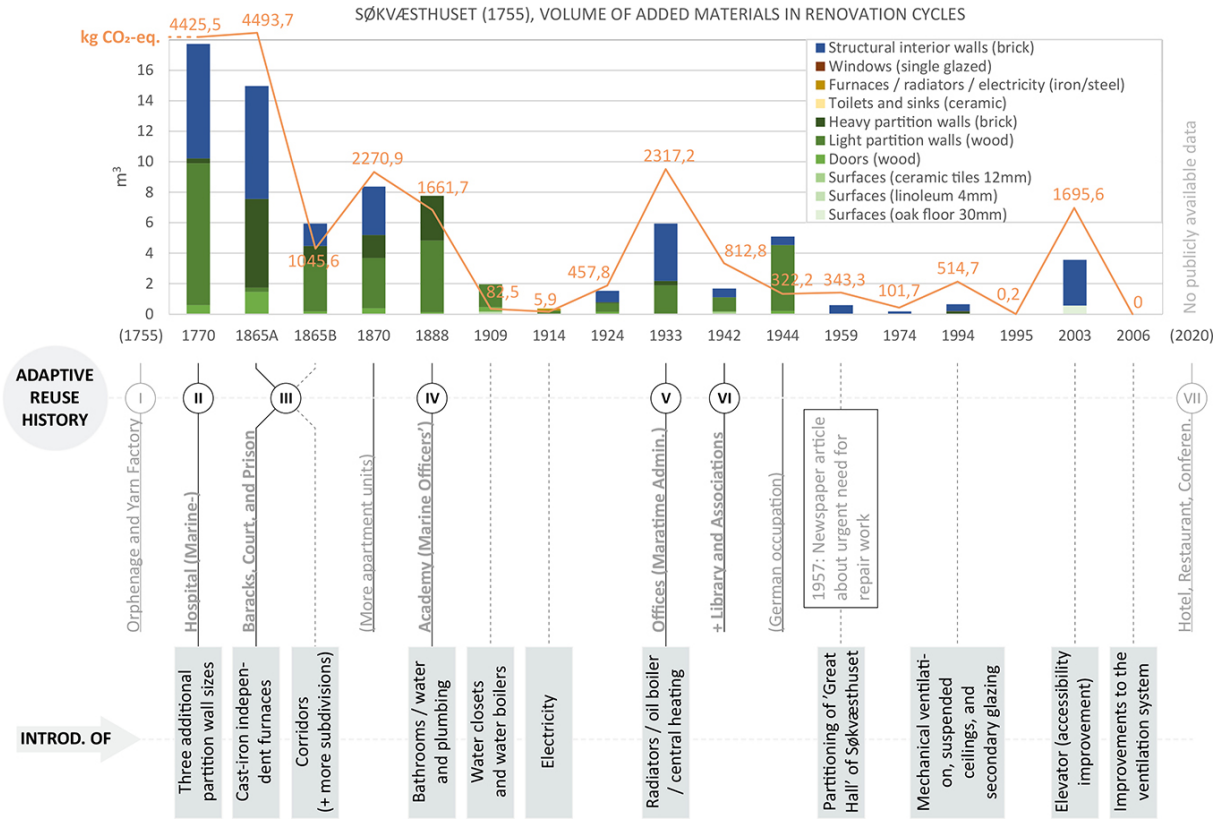


Figure 2: Søkvæsthuset: The transformation history, material uses in m^3, and metabolism. Source: (1st author 2024)

4.2. Tingbjerg Family Housing's metabolism (1958-2023)

Services was the longest lasting layer in Tingbjerg Family Housing, followed by Scenery / Space Plan, and Shell / Skin+Structure. Since changes were happening most rapidly in the Shell / Skin+Structure, and then Scenery / Space Plan, the case deviates from both Duffy's and Brand's models. The replacement of the Shell's windows and wood frames to double glazed windows in PVC-frames was the biggest CO_2-emmitter, closely followed by the structural changes to the façade. Had the outer part of the cavity wall not been rebuilt with reused bricks, its impact would have nearly doubled. Services had the second lowest metabolism with the addition of new radiators, mechanical ventilation, and bathroom fittings. The Scenery's addition of light partition walls contributed the least to the metabolism. Yet, had the furnishings been included in the study (see 4.5), the Scenery would likely have had a larger metabolism than Services, with the addition of new kitchens (see Figure 3).

4.3. Tingbjerg Dormitory's metabolism (1972-2012)

In Tingbjerg Dormitory, the Scenery/Space Plan and the Services were, surprisingly, the most lasting layers. Relative to the other cases, however, their lifespans were low: thoroughly reconfigured in 2012, just 40 years after their construction. These layers were followed by the Structure (in-situ cast concrete) which was lightly improved on in the first renovation of 1992 and again partially in 2012, while the Skin was replaced and altered thoroughly two times in the studied period (1992 and 2012). Neither Duffy's nor Brand's theoretical models were predictive of the sequence of change, yet Tingbjerg Dormitory followed Brand's separation of the Shell into Skin and Structure-layers with notably diverging lifespans. The metabolisms of layers in Tingbjerg Dormitory followed the lifespan order (see Figure 3): The Skin accounted for 2/3 of the total metabolism, with the exchange of windows as the main event, followed by fibre cement cladding, galvanised steel rails, and a balcony staircase (also galvanised steel). The Structure accounted for 1/5 of the metabolism, where the biggest contributor to the metabolism was the extension of the concrete deck beyond the existing balcony for the extension of the kitchens, and secondarily the structural steel balcony deck in front of the common kitchens. While Services was the second lowest contributor to the metabolism of Tingbjerg Dormitory, its metabolism was still six times higher than in Tingbjerg Family Housing per m^2/year. The Space Plan contributed the least to the metabolism. However, had the new kitchen cupboards in the common kitchens and the kitchenettes in the dorm rooms been included in the study (see 4.5), the environmental impact of the Space Plan layer would have been greater.

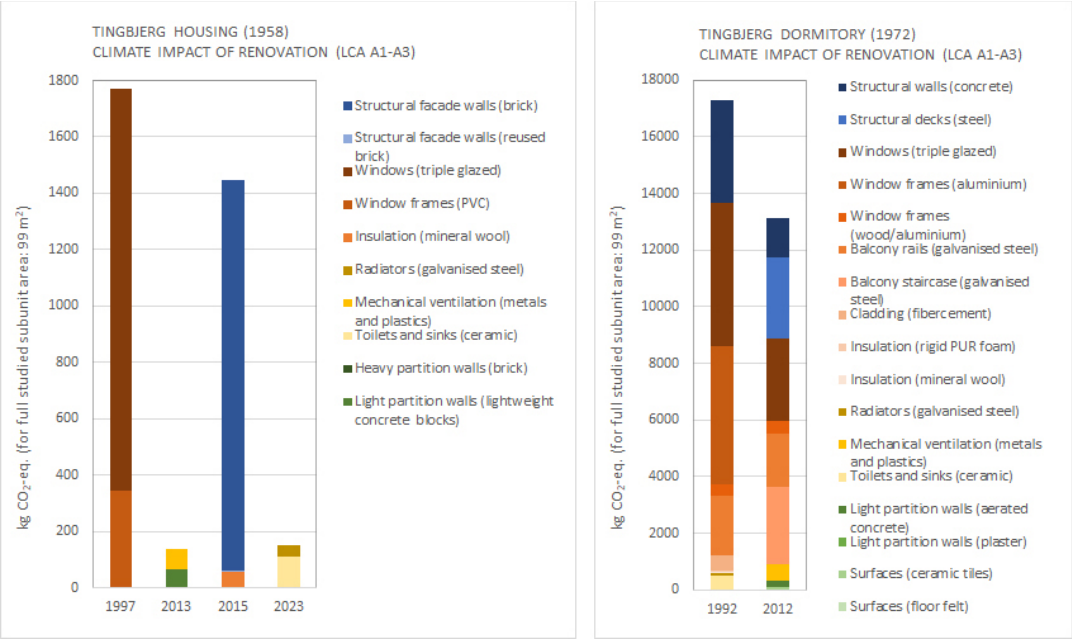


Figure 3: Tingbjerg Family Housing and Tingbjerg Dormitory: Metabolisms (in kg CO_2-eq). Source: (1st author 2024)

4.4. CO_2 and lifespans across cases

The assessment of the case metabolisms (kg CO_2-eq./m^2/year) had the following results: Søkvæsthuset's metabolism (0,43 kg) was 11 times lower than the Dormitory's (4,83 kg), whereas only 1,25 times lower than the Family Housing (0,54 kg) (see Figure 1 in 4.0). If viewed by m^3 material per m^2/year, the order comes out differently: the Family Housing (0,0013 m^3), Søkvæsthuset (0,0017 m^3), and the Dormitory (0,0019 m^3). This shows that the materials used in the metabolism of Søkvæsthuset are generally low-CO_2 compared to materials used in Tingbjerg Dormitory that used high-CO_2-materials like metals and glass (Figure 4, left side). With the marginal metabolic difference between the control case and Søkvæsthuset, the differences in locations, weathering conditions, design quality levels, maintenance/repair cycles, and programmes did therefore not challenge the robustness of the results.

The sequence of change of building layers differed from both Duffy and Brand's models in the three cases. Brand's change categories did not correlate with any of the cases but came closest to that of Tingbjerg Dormitory, while Duffy's model matched Søkvæsthuset's (Figure 4, right side). An overall trend from the oldest to the newest case was the increasing metabolism and shortening of lifespans of the Skin/Shell (Figure 4, right side). In Søkvæsthuset, the façade was not renovated/adapted except for the addition of secondary glazing where openable single glazed windows in wood frames were added on the inside in 1985 (12 % of façade area). Windows were replaced in the Tingbjerg Family Housing in 1997 to higher energy-performance windows (24% of the long façade areas), and most of the façade including walls/windows was replaced in the Tingbjerg Dormitory in 1992 (64% of the façade area) and in 2012 (38% of the façade area), both as energy-upgrades and for outwards expansions (see Figure 1 under 4.0). From almost no changes and the longest lifespan in Søkvæsthuset, the Skin had the shortest lifespan and highest metabolism in the two other cases. In Søkvæsthuset, the Structure had the second longest lifespan while the second shortest in the Dormitory. The Space Plan changed most frequently in Søkvæsthuset.

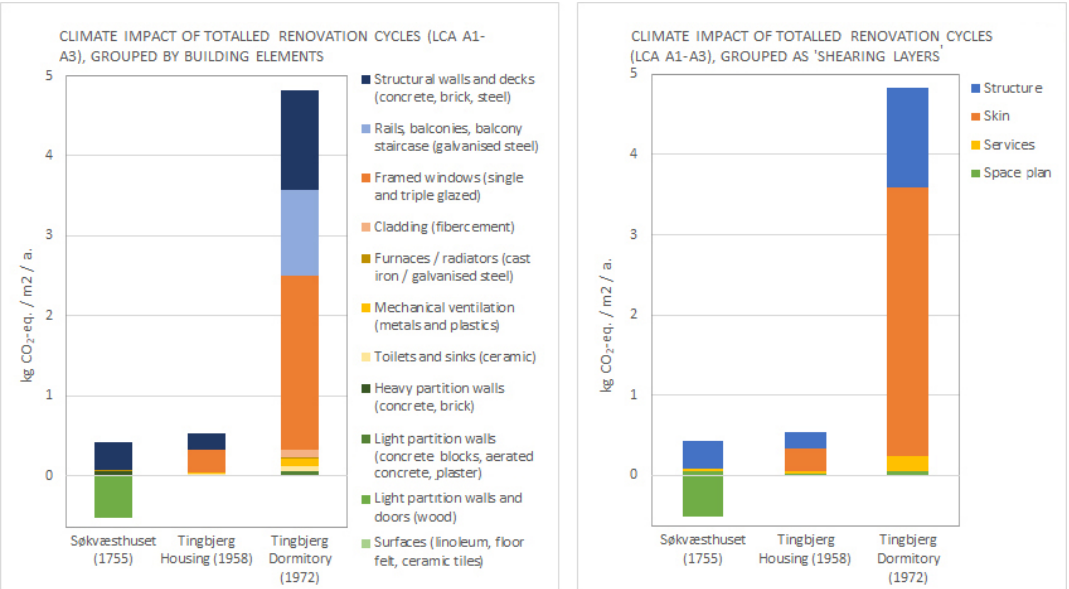


Figure 4: Metabolisms of all cases by components and by layers (in kg CO_2-eq/m^2/year). Source: (1st author 2024)

4.5. Limitations and uncertainties

- Furnishing with drawers, cupboards, tables, and shelves were not included in the calculation because of varying data quality on materials, material thicknesses, and dimensions.
- All wood (e.g. in Fig. 4) was left out of the calculation for all cases since the lifespans of wood and traditions of reuse diverge greatly between preindustrial and industrialised building cultures (Bak-Andersen 2020).
- The addition of an elevator in Søkvæsthuset in 2003 improved the accessibility of the building compared to the other two cases, which did not have elevators. Because of the different levels of accessibility between the cases, the elevator itself is not included in the calculations, only its changes to the structure and surfaces.
- Embedded units are samples and thus not 100% representative of each case which could impact the results.

5.0 ANALYSIS AND DISCUSSION

Brand's and Duffy's models of lifespan categories differ in what is a crucial point for this study. In Tingbjerg Dormitory, the separate Skin- and Structure-layers gave rise to a high metabolism, whereas Søkvæsthuset's singular Shell-layer – a solid fired brick wall – had a remarkably long lifespan and a low metabolism over 250+ years. Tingbjerg Family Housing's Shell is somewhat in-between the two paradigms: There are no multi-layered light façade-panels, but the layering of its brick cavity wall enabled post-insulation of the gable facades with mineral wool in the cavity. The differences between the three cases indicate an overall shift in the building culture's view of the façade – from a singular Shell to Skin+Structure-layers. While not a surprising finding in itself, the different wall types' frequencies of change showed that lifespans relate less to fixed groupings of building components as in Duffy and Brand's models, but rather to the architectural character of building components, their respective capacity for alteration, and the architectural/structural relationship between components. In the following, this is explored further in a comparison of wall types across the cases using Moneo's relationship of structural logic and architectural principle as an analytical lens.

In Søkvæsthuset's nearly 1-meter-thick symmetrically and rhythmically ordered façade walls, the architectural principle of lesenes that divide the façade into segments, each with a row of windows, reveals the structural logic of walls that thicken to carry more loads. The half meter thick inner structural walls, also in brick, are from both architectural and structural perspectives secondary to the façade walls. Less expressive of an architectural order and structural logic, door openings have been moved, and the built-in shafts resized over time. However, the inner structural walls organise the overall spatial layout, such as room depths, circulation, and distribution of shafts (which originally constrained room sizes in relation to heating sources). The architecturally and structurally tertiary original wood plank partition walls of 12 cm in thickness spanned between the principal and secondary walls and required the least amount of effort to change and move over time, which also made them the most frequently changing wall type. The significant architectural differences between the three wall types – from heavy mineral to light biogenic materials and with wall thickness ratios approximating 1:2:8 – coincide with their respective levels of change. The lightest and most easily changeable wall type was physically altered the most, where the heavier walls resisted physical alteration in meeting shifting needs. For example, the incredibly "stubborn" façade wall – which would probably seem like a nightmare in the view of most Circular Economy design frameworks like Design for Disassembly (Guldager and Sommer 2018) – has accommodated an orphanage, a hospital, military barracks, an academy, offices, a hotel and more, with next to no physical changes. From the perspective of adaptability and design-for-disassembly, this shows that all three wall types do not need to be physically altered to the same extents to meet shifting user needs, to adjust to evolving indoor climate comfort standards, and to adapt to new uses. There is a *"hierarchy of alterability"* where the structural logic and architectural principle intercept and facilitate different frequencies of change for each building component type over time. This hierarchy of alterability is in Søkvæsthuset experientially emphasised through form (thick walls and niches vs. thin, less sculptural partition walls), structure (thicker walls carry more loads), and materials (heavy mineral materials which feel cold to touch vs. light and alterable biogenic materials which feel warmer).

Tingbjerg Family Housing's walls have a similar hierarchy of alterability which coincides with the frequencies of change for each component type. The structure is a traditional brick cavity wall, in which Skin and Structure are one and the same. The 36 cm thick structural cavity walls have a monolithic and massive appearance, with windows and door openings as punctuations on the otherwise flush surface of the body of the building. The 18 cm thick inner structural walls are of bricks and have remained largely unaltered with the exception of door holes and openings around built-in wardrobes, whereas the 8 cm thick aerated concrete walls and wood cabinet walls were of lighter materials and altered the most with the expansion of kitchens into the corridor/entry. The ratio between the three wall types approximates 1:2:4, which is roughly also the ratio of change and of structural/architectural importance.

In the hierarchy among wall types in Tingbjerg Dormitory, the relationship between architectural principle and structural logic is not as legible as in the other two cases. The Structure's 15 cm thick walls of reinforced concrete are perpendicular to the façade and slightly *thinner* than the non-structural façade walls. At the same time, the structural in-situ walls are spatially unarticulated; hidden from the outside and plastered over from the inside. They were altered where dorm rooms were fused as well as around staircases and common kitchens where decks were expanded. The 19 cm thick non-structural façade walls are composed of four different façade wall build-ups, each with their own intricate layering of materials. While parts of the structural façade look structural, and were only partially reclad, the parts looking decidedly non-structural were replaced two times in just 40 years. The 8 cm thick partition walls in aerated concrete bricks are only slightly thinner than the structural walls and were altered to about the same degree as the structural walls. The difference between the depth of the structural walls (experienced through door openings), the non-structural façade walls (seen through windows), and the light partition walls (experienced through door openings) is minimal – the ratio of the three wall types approximates 5:3:8 (structure : facade : partition). The order of the most frequently changing component types are the opposite of the order in the

two other cases: the building envelope changed the most, then structural inner walls, and least the partition walls. Thus, in the absence of a hierarchy of alterability, the Dormitory continually met user needs through physical alterations of some of the more laborious, costly, and environmentally taxing elements, which drove up its overall material use and metabolism.

The paper proposes a *"hierarchy of alterability"* to differentiate the level of change among building components and parts, and, at the same time, meet future uses and needs. The hierarchy of alterability is present in both of the preindustrial cases, Søkvæsthuset and Tingbjerg Family Housing: The least architecturally and structurally significant building component types have changed the most and vice versa. The presence of this hierarchy lowered the overall material consumption and the environmental impacts compared to Tingbjerg Dormitory where a hierarchy of alterability was lacking and obscured. Where Duffy/Brand's models define frequencies of change by families of building parts e.g. Skin, Space Plan or Structure that act independently from each other, this paper suggests a different explanation of change, which appeared as a more consistent pattern across the cases. Degrees of change depend on the relationship between components and their respective degree of alterability. In other words, the alterability of the individual component is contextually dependent on the alterability of other components, cutting across Duffy/Brand's building layers. The degree of alterability is, in part, defined by how present the relationship between architectural principle and structural logic is – from structural and architectural significant to non-structural and architecturally subservient. And in part by how well components are architecturally differentiated to express and experientially emphasise their respective margins for alteration so that generations of users and building owners can recognise, feel, and value this hierarchy of alterability across building cultures.

Beyond Duffy and Brand's widely used models of change (e.g. in Le Den et al. 2020; Danish Government's Climate Partnerships 2021), the hierarchy of alterability challenges influential design frameworks of the Circular Economy paradigm on how to understand and facilitate change in buildings to lower their environmental impact and evolve with changing needs. One such example is Design-for-Disassembly where all components should be designed for non-wasteful/non-destructive/easy disassembly to give future users a maximum of freedom to physically change buildings to meet their needs (Lysgaard Vind 2024; Guldager & Summer 2018; Crowther 2005). However, this paper found that the levels of adaption to new uses did not require all building components and parts to be physically alterable to the same extents. Rather, the case studies showed that when a building did not clearly differentiate the alterability of components, the consumption of building materials and the environmental impacts were significantly higher. When the margins of freedom of physical alteration were differentiated across components and building parts in a clear hierarchy of alterability, adaptation to new uses and needs was possible with a lowered consumption of materials. Within the hierarchy of alterability, frameworks like Design for Disassembly could be applied selectively to those building parts which are intended to have the most frequent physical alterations. Thus, the paper proposes the hierarchy of alterability as a novel design framework for the design of new buildings, or for the transformation of existing ones, to break with an excessive consumption of building materials in renovations and adaptations cycles and thereby lower the metabolism in a 200+years perspective.

CONCLUSION

The paper quantitatively analysed the environmental impacts from the material use – the "metabolism" – in the use-stage of three public multistorey housing buildings in Copenhagen from different building cultures. The three cases were the premodern, preindustrial Søkvæsthuset (1755), the fully industrialised Tingbjerg Dormitory (1972), and the preindustrial Tingbjerg Family Housing (1958) as a control case right before industrialised construction methods became prevalent. Environmental impacts were calculated of all added building materials' LCA A1-A3 phases with today's CO_2-eq factors, using each component's actual, observed lifespan. It found that the preindustrial, premodern case Søkvæsthuset, despite its many adaptive reuses, had a metabolism that was 11 times lower than that of the fully industrially constructed Tingbjerg Dormitory, and slightly lower than that of the control case. With this data and through drawn mappings of spatial changes across all cases, the relationships between architectural characteristics and patterns of change were qualitatively interpreted with several theoretical models of building change: Duffy and Brand's models of layers of change in buildings and Moneo's theoretical proposition of an alliance between structural logic and architectural principle. The paper found that differences in architectural characteristics from different building cultures greatly influenced the frequencies of change and the metabolism results. Neither Duffy's nor Brand's models of change predicted the frequencies of change in the three cases, while Moneo's hierarchy of structural/architectural significance of building components emerged as a better explanation of how the cases changed. A particular design principle of low metabolism was identified: to differentiate the dependency of structural logic on architectural principles in a *"hierarchy of alterability"* that is experientially emphasised through form, structure and materials. By design, some components adapt to new uses and needs through ease of physical alteration and others adapt while actively resisting physical alteration.

More broadly, these results show the potential value of empirically grounded architectural design knowledge in the context of reducing the environmental impact and material consumption. Specifically, the paper challenged Brand's model of change in buildings where separable building layers act and change independently and proposed instead that change follows the relationship and hierarchy of alterability between building components. This hierarchy also challenged Design-for-Disassembly as a blanket sustainability design strategy and rather proposed a more selective use of it. The hierarchy could be used for different purposes: To lower the operations costs or environmental impacts by distributing costly or reuseable/low-carbon materials according to where changes are most frequent. Or, for architects to prioritise time, budgets, and design efforts by focusing on the hierarchy of alterability itself and the longest lasting building parts where architectural quality matters most in the long run. There is a need for further research into the relationships between hierarchies of alterability and changing user needs over time, as well as to study more factors influencing patterns of change. There is also a need to study patterns of change and hierarchies of alterability among more cases and more building parts e.g. installations and interiors.

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Introducing Bamboo as a Building Material in Architecture Education of Aspiring Young Building Designers for Sustainable Community Development

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ABSTRACT: To address global challenges like climate change, pollution, and social inequality, we must broaden our thinking and train the next generation of leaders—young students. Introducing bamboo as a building material through architecture education is one way to explore its potential and promote sustainable practices. This paper focuses on the role of architectural education in teaching aspiring students about bamboo materials for sustainable community development, through a participatory bamboo installation project. In this initiative, a group of students worked in five teams, each consisting of five members, to design structures using bamboo—a sustainable, indigenous material. Over time, their designs evolved during review sessions, from simple to complex, and from basic forms to more creative, student-generated structures. They moved from small-scale models to larger ones, eventually constructing a real-scale structure. These hands-on, interactive exercises fostered great enthusiasm among the students and professors, moving beyond theoretical learning. Workshops, talks, and presentations were held to explore the stability of skeletal systems in creative ways. The newly built models, featuring different joists, knots, weaving patterns, and construction techniques, allowed the students to test their theoretical ideas. The tactile qualities and construction potential of bamboo and other locally available materials became evident, highlighting their practicality. This study also aims to identify gaps in research on bamboo as a sustainable material for community development. While bamboo has been explored in some areas, it remains underinvestigated in others. By considering bamboo as an eco-friendly building material, this project aligns with the low-carbon movement and encourages young leaders to adopt sustainable practices. The practical experience provided a deeper understanding of these issues than theoretical lectures ever could, making the students and instructors more aware and knowledgeable about bamboo's potential for sustainable architecture.

KEYWORDS: architecture and education, installation, bamboo, building material, sustainable community development

INTRODUCTION

In the pursuit of sustainable architecture and community development, the introduction of bamboo as a building material holds immense promise. This initiative seeks to transform architectural education for aspiring young building designers by integrating the principles of sustainability and innovation. Bamboo, renowned for its rapid growth and eco-friendly properties, emerges as a viable alternative to conventional construction materials (Rampal et al. 2023).

This shift in architectural education aims to equip future designers with a deep understanding of bamboo's structural capabilities, versatility, and environmental benefits. Students will explore bamboo construction, applying sustainable design principles through hands-on learning. Integrating bamboo into the curriculum aligns with the global push for eco-friendly construction and sustainable development.

This initiative not only addresses the environmental footprint of traditional building materials but also nurtures a sense of responsibility among young designers to create structures that harmonize with nature. The ultimate goal is to produce a new generation of architects who can contribute to the development of communities that thrive in harmony with their ecological surroundings (Behnejad 2022). Unfortunately, the use of bamboo in traditional houses is declining, replaced by materials like concrete and steel. Bamboo is often seen as less practical, modern, and durable, with some considering it suitable only for lower-middle-class homes. This shift is reflected in the decreasing number of bamboo houses in local communities. A prevailing assumption exists that bamboo dwellings are unsuitable for habitation and are exclusively associated with poverty (Lopez 2003).

Hence, architecture education emerges as a potential avenue to acquaint the community with bamboo, presenting it as a regional resource that is eco-friendly, abundantly available, and possesses exceptional aesthetic qualities. This initiative, represented by the installation, serves as a means to familiarize students with bamboo, encouraging them to envision a sustainable future and integrate this versatile material into their design considerations (Xiang et al. 2021).

Through this introduction of bamboo as a fundamental building material, architecture education becomes a catalyst for positive change, inspiring young designers to forge a path toward a more sustainable and resilient future in community development.

1.0 BACKGROUND AND RATIONALE

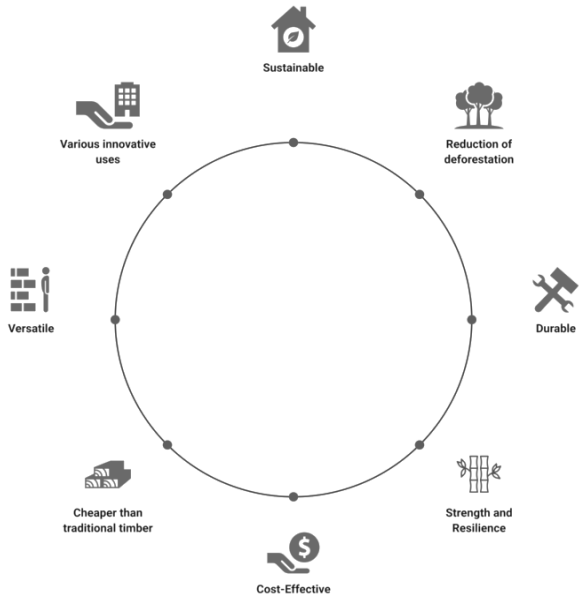


Figure 1: Using Bamboo as construction material. Source: (Ryan 2023)

1.1 Evolution of bamboo use in construction

Bamboo has a rich history as a construction material, evolving over centuries to become a sustainable and versatile option. In ancient civilizations, bamboo was utilized for its inherent strength and flexibility, supporting structures and providing shelter. The simplicity and abundance of bamboo made it an accessible choice for various building needs. Over time, traditional building techniques were refined, and bamboo became a staple in vernacular architecture (Mohan, Dash, and Boby 2022). In contemporary contexts, the evolution of bamboo as a construction material has been influenced by ecological awareness and sustainable design principles. Modern engineering and treatment methods enhance bamboo's durability, making it an attractive alternative to conventional materials. Architects and builders today recognize bamboo's potential in creating eco-friendly, resilient structures, contributing to a more sustainable built environment (Fahim et al. 2022). The utilization of bamboo necessitates a creative approach and an openness to natural materials, positioned as fundamental elements in the future economy. These materials not only embody the shifts occurring due to innovative ideas and solutions but also align with the transformative industrial evolution and technological progress (Wu and Fan 2021).

1.2. Contemporary challenges in building material choices

Contemporary architecture faces an array of challenges in selecting building materials, driven by dynamic considerations such as environmental sustainability, technological advancements, and societal demands. One central challenge lies in mitigating environmental impact, addressing issues like carbon emissions, resource depletion, and waste generation. This necessitates a shift towards materials that contribute to a more sustainable and eco-friendly built environment (McDonough and Braungart 2002). In its function, architecture intentionally harmonizes with the environment of each region and historically develops innovative solutions when faced with challenges. Occasionally, these challenges become opportunities, transforming architecture into a form of art. Climate change has significantly influenced the adaptation of shelter and materials in this region. Vernacular architecture has evolved and integrated itself into the welfare of its inhabitants through a profound understanding of the environment and responsive human systems (Doza and Ema 2019) . Hence, There is a need to explore the challenges of integrating green building principles into construction practices. It emphasizes the need for environmentally responsible material choices and offers insights into sustainable design strategies (Maslucha et al. 2020).

1.3. Need for sustainable alternatives in architecture

The imperative for sustainable alternatives in architecture has become increasingly pronounced as global awareness of environmental issues continues to grow. In endorsing the cradle-to-cradle philosophy, architects are prompted to rethink their material choices, focusing on those that offer not only durability and functionality but also environmental responsibility. The shift towards perpetually recyclable or biodegradable materials in building design aligns with contemporary ecological imperatives, fostering a holistic approach that considers the entire lifecycle of architectural elements (McDonough and Braungart 2002). The integration of sustainable materials further enhances the ecological sustainability of bio-climatic design. By prioritizing materials with low environmental impact and long-term durability, architects can contribute to reducing the overall ecological footprint of buildings. This aligns with the broader goals of sustainable architecture, emphasizing a holistic approach that considers both immediate energy efficiency and the long-term environmental implications of architectural decisions (Chen et al. 2009). Encouragement is given to transcend a narrow focus on green building technologies and materials. Instead, architects are prompted to adopt a more inclusive and socially conscious approach. The adoption of this comprehensive framework positions architects to contribute to the creation of built environments that not only

minimize their environmental impact but also promote social inclusivity and ensure economic sustainability (Souza and Meirelles 2021). This shift in perspective signifies a departure from the conventional concentration solely on environmentally sustainable aspects in architecture. Furthermore, the call for economic sustainability underscores the importance of ensuring that architectural decisions contribute positively to the long-term financial viability of projects. Architects are encouraged to consider the economic implications of their designs, fostering the development of built environments that are not only environmentally conscious and socially inclusive but also economically resilient (Elkington 1997).

2.0 INSTALLATION PROJECT DESIGN AND CONCEPT

This bamboo installation project at BRAC University's Savar campus serves a dual purpose: introducing bamboo as a viable building material in architecture education and creating sustainable learning spaces.



Figure 2: Location of BRAC University Residential Campus. Source (Author 2024)

Through hands-on experience, students explore bamboo's structural capabilities, environmental benefits, and potential in modern design. Workshops and faculty-led talks enhance their skills in sustainable architecture. The installation serves as a living laboratory, fostering creativity and aligning with the university's holistic education approach. The project highlights bamboo's versatility, with designs like archways and shelters, while faculty reviews ensure safety and durability. Students also learn to source bamboo responsibly and use eco-friendly construction techniques, minimizing waste and promoting reusability. Informative signage educates the community about bamboo's benefits. This project encourages students to take ownership of sustainable initiatives beyond the classroom.

3.0 METHODOLOGY

The installation project aimed to introduce bamboo as a building material to aspiring young designers at BRAC University through a collaborative, student-centered approach. It began with a review of scaled models and existing studies on bamboo construction and sustainable architecture, followed by hands-on design sessions to engage students with bamboo techniques. Briefing sessions on bamboo's cutting and knotting processes allowed students to explore its structural and aesthetic potential. Local market surveys and literature reviews gathered feedback on students' learning experiences, ensuring the project was responsive to their needs. The project concluded with a public exhibition showcasing sustainable designs, raising awareness about bamboo as a viable building material for sustainable architecture.

4.0 IMPLEMENTATION

4.1. Execution of the installation project

The execution of the installation project by students, commencing with concept generation and progressing through the design process to construction, is a dynamic and participatory endeavor. In the initial phase, students are encouraged to unleash their creativity in generating innovative concepts for the project. Collaborative brainstorming sessions foster a collective spirit where diverse ideas are shared and refined, emphasizing sustainability and community-centric design principles.



Figure 3: Preliminary scaled models for the installation project. Source: (Author and Students 2021-2024)

Students participate in hands-on workshops to turn their concepts into detailed plans, often using digital modeling tools to refine designs while considering bamboo's structural and environmental benefits. They then create small-scale prototypes for practical experimentation. During the construction phase, students actively engage in on-site activities, bringing their designs to life under expert guidance. Community involvement is essential, fostering local support and understanding. The project concludes with a final exhibition, where students present their completed installations, sharing insights and sustainable design principles. This experience enhances their technical skills and deepens their understanding of architecture's social and environmental impacts.

4.2. Student involvement and learning outcomes

Student involvement in the installation project offers a transformative learning experience, fostering creativity through collaborative brainstorming and enhancing design skills with workshops and digital tools. The hands-on construction phase develops practical bamboo construction, planning, and execution skills. Collaborative teamwork promotes effective communication and shared responsibility, while engaging with local communities helps students understand the social impact of their designs.

The project also serves as a conduit for developing project management competence, as students actively participate in material sourcing, planning, and execution. Encouraging documentation and reflection throughout the process promotes critical thinking, allowing students to assess challenges, celebrate successes, and internalize valuable lessons.



Figure 4: Students actively participate in each step of construction. Source: (Author and Students 2021-2024)

The final presentation and exhibition provide a platform for students to refine their presentation and communication skills, articulating design concepts and the sustainable aspects of their installations to diverse audiences. Ultimately, the sense of achievement and pride derived from successfully completing the installation project solidifies students' confidence and readiness to contribute meaningfully to the fields of architecture and sustainable community development.



Figure 5: Completed installation projects. Source: (Author and Students 2021-2024)

4.3. Contribution to sustainable community development

The installation project promotes eco-friendly architecture and community engagement by incorporating bamboo as a sustainable building material. Students contribute to environmentally conscious design, while interactions with local communities foster inclusivity and social responsibility.



Figure 6: Students engaging with the construction techniques . Source: (Author and Students 2021-2024)

The installations serve as prototypes, demonstrating resilient architectural solutions and promoting the creation of sustainable communities that balance environmental, social, and innovative needs.

4.4 Long-term effects on architecture education

The installation project's long-term impact on architecture education is transformative. By immersing students in hands-on experiences with bamboo construction, it reshapes traditional pedagogical approaches. The emphasis on sustainable design principles becomes ingrained, influencing future architects to prioritize eco-friendly solutions. Integrating digital tools enhances technological literacy, ensuring graduates are well-versed in innovative practices.

The collaborative nature of the project cultivates teamwork and communication skills, preparing students for the interdisciplinary demands of the architectural profession. Overall, the project sparks a paradigm shift, fostering a new generation of architects who approach education with a holistic understanding of sustainability, practical skills, and community engagement.

5.0. LEARNING OUTCOME AND ASSESSMENT METHOD

Students gained proficiency in bamboo joinery techniques, mastering skills like lashing, weaving, and structural connections while exploring bamboo’s renewable nature and low carbon footprint. They were encouraged to innovate within sustainable design constraints and collaborate across disciplines. Critical thinking was fostered through reflective practice on environmental and social impacts.

Assessment focused on both practical skills and theoretical knowledge. Students' construction abilities were evaluated based on precision and integrity, while design presentations assessed their sustainability solutions. Peer evaluations and instructor feedback guided collaboration and innovation.

Overall, the project enhanced students' bamboo construction skills, fostering collaboration, critical thinking, and innovation to address global challenges and position them as future leaders in sustainable architecture.

6.0. RESULTS AND DISCUSSION

The exercise exerts a profound influence on sustainable design practices within the context of architecture. It shifts paradigms by introducing students to bamboo as a viable and eco-friendly building material, fostering a fundamental change in their approach to design. The exercise cultivates a heightened awareness of sustainable principles as students engage in hands-on experiences and collaborative design processes. The influence extends to the integration of sustainable elements in architectural designs, where bamboo becomes a central feature. The exercise prompts students to consider not only the aesthetic aspects of their creations but also the environmental impact, resource efficiency, and resilience. This newfound perspective encourages innovative solutions that prioritize sustainability in building practices.



Figure 7: Introducing students to bamboo as a viable and eco-friendly building material. Source: (Author and Students 2021-2024)

Moreover, the exercise encourages a holistic understanding of sustainability, encompassing social, economic, and environmental dimensions. By engaging with local communities during construction, students recognize the importance of designing structures that harmonize with the socio-cultural context, reinforcing the interconnectedness of sustainable architecture and community well-being. In summary, the exercise significantly influences sustainable design practices by instilling a deep appreciation for eco-friendly materials, fostering interdisciplinary collaboration, and promoting a holistic approach to architecture that aligns with the principles of sustainability.

7.0. LIMITATIONS

A limitation of these installation projects is their potential lack of scalability and generalizability beyond specific educational settings or localized contexts. While they offer valuable hands-on experiences and insights into bamboo construction techniques, the outcomes and lessons learned may not easily translate to broader applications or diverse geographical regions. Therefore, while these installation projects are beneficial for educational purposes, their broader impact and applicability in sustainable community development initiatives may require further consideration and refinement.

8.0. FUTURE DIRECTIONS

There are several promising avenues for further research and development within the initiative focused on bamboo construction. Firstly, advancing bamboo construction techniques through innovative joinery methods, structural systems, and treatment processes is crucial for enhancing efficiency and applicability in diverse architectural contexts. Secondly, integrating bamboo into architectural education demands comprehensive efforts such as developing educational frameworks and interdisciplinary courses to ensure students receive thorough training on this sustainable material. Lastly, conducting longitudinal studies to assess the long-term impact of bamboo construction on sustainable development goals, including environmental, social, and economic outcomes, will provide valuable insights into its contributions to sustainability. These areas of focus promise to advance the adoption of bamboo as a sustainable building material and underscore its role in global sustainable development efforts.

CONCLUSION

In conclusion, this research has yielded valuable insights into the potential of bamboo as a sustainable building material and its implications for architecture education. The key findings highlight the versatility, durability, and eco-friendliness of bamboo, underscoring its importance in addressing pressing environmental challenges and promoting sustainable architecture. By integrating bamboo into architectural education, students are empowered to prioritize sustainability, nurture creative thinking, and engage with local communities, thereby shaping a more resilient and equitable built environment. Moving forward, there is a clear call to action for future initiatives. It is imperative to continue refining bamboo construction techniques, integrating bamboo into the architectural curriculum, and assessing its long-term impact on sustainable development goals. By embracing these initiatives, we can accelerate the adoption of bamboo as a sustainable building material and pave the way for a more sustainable and socially responsible future in architecture.

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Advancing Transitional Shelter Provision Through Innovative Structural Solutions

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ABSTRACT: The overarching goal of this study is to equip researchers and developers in the structural and associated sectors with the information they need to prioritize, in the creation of suitable and effective aid for emergency housing that can keep up with the projected future increase in demand. Using the grounded theory method and a series of case studies, the paper presents a compiled list of user-reported structural problems, the difficulties authorities have had in resolving those problems, and some ideal solutions, derived from the theoretical coding. The emergency shelter requirements in this study highlight the need for an economic (cost-effective), lightweight, reusable (especially if transitional), easily and efficiently manufacturable, constructable (with few in-situ installation inputs) and transportable housing solutions. Based on the structural requirements identified and acknowledged, a spectrum of innovative structural approaches, including modular and adaptable systems, site-specific designs, hybrid materials, and sustainable construction techniques have been proposed as to facilitate the development of new shelter designs and to support and enhance the usability of existing designs. These approaches emphasize the integration of advanced materials, computational tools, and resilient design principles to create shelters that are not only robust and safe but also environmentally conscious and culturally sensitive. Finally, the paper summarizes the key concerns in terms of sustainability and structural aspects of proposed designs and concludes with recommendations and suggestions to enhance the applicability of such designs, based on emergency requirements and shelter deployability. This article catalyses transformative change in the field of emergency shelter provision serving as the base for confrontation on alternative designs and materials and will support further studies on the structural and architectural design and organization of emergency shelter provisions.

KEYWORDS: Shelter Emergency, Post-disaster, Emergency Housing, Sustainable Structures, Timber – Steel Composite.

1.0 INTRODUCTION

Emergency shelters become crucial when living conditions fall below humanitarian standards. However, most crises last significantly longer than anticipated, over 80% of refugee situations extend over ten years, and stabilization in conflict-affected regions can take upwards of 23 years (European Commission 2017). With climate change and global conflicts exacerbating displacement, durable transitional solutions are increasingly critical (United Nations Office for Disaster Risk Reduction 2022). Transitional shelters are those aimed to offer habitable, secure, safe, and healthy living spaces as an initial step towards recovery, even amidst prevailing uncertainties bridging the gap between temporary stay and permanent housing (Corsellis 2012). They are put in place when loaning mechanisms and accompanying measures to enhance the resilience of the affected population are not possible. Research on transitional shelters is fragmented, with design strategies varying widely across contexts (Beatini et al. 2022; Cerrahoğlu and Maden 2022; Beatini 2015) and the design community leaning toward adaptable solutions. The civil engineering community leans towards prefabrication (Pan 2022) and emphasizes structural testing (Caimi et al. 2014). Occasionally, these approaches conflict; for example, the push for testing clashes with the use of local materials like earthen blocks or timber, which may lack fully explored structural properties and construction techniques. a notable gap persists in research addressing the challenges of designing transitional shelters under uncertain conditions. Post evaluation surveys have been promoted as a mean to contextualize solutions (Portieles 2021), but Transitional shelters are the most challenging to design because they must address issues akin to permanent housing within an uncertain timeframe, with constrained budgets and shorter construction periods. The risk of either overdesigning or substandard construction is notably high.

In a previous study (Beatini et al. 2022), we employed Grounded Theory Analysis to create a knowledge base of structural-related challenges. That analysis involved mapping 84 emergency shelters used in actual emergency scenarios and led to the identification of persistent structural-related challenges. Those results are here translated in design principles and criteria to propose innovative structural solutions. An innovative structural design for transitional shelters is conceptualized, combining steel and timber. This mixed-material design minimizes steel usage to enhance structural stability and reliability—key challenges in lightweight shelters. By integrating standardized light gauge elements, the design not only aims to improve viability and feasibility but also holds the potential to significantly boost sustainability on a broader scale.

2.0 MATERIAL AND METHOD

2.1 The transitional shelter typology

Shelters can be classified either as temporary sheltering, transitional, or permanent housing, Figure 1. According to the classic definition in (Quarantelli 1995), the first is a temporary stay arrangement such that the person suspends daily activities. Transitional shelters are temporary housing arrangements such that the persons recover routines but are supposed not to stay permanently. Finally, permanent housing is the institutionalized restoration of permanent residential conditions, often through the construction of a permanent yet small space, or 'one-room shelter'. A common form of temporary shelter is the tent, for which international agencies have provided increasingly optimized solutions. These solutions are adaptable to the specific climate challenges of different scenarios (UNHCR 2016). An illustrative example of permanent housing is the terraced Villa Verde houses in Chile, designed by Elemental (O'Brien and Carrasco 2021). Each house can be expanded vertically by the owners at their own pace. Transitional shelters were first implemented on a large scale in 2005, following the South Asia Tsunami (Corsellis 2005), as a strategic response to avoid expensive cycles of delivery of temporary shelters. The varied duration of this period for individuals complicates efforts to maximize their benefits and sustainability (Flores and Kloer 2012).

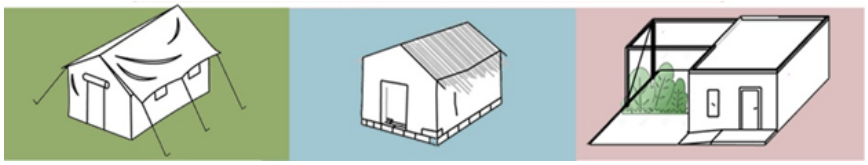


Figure 1: From left to right, a pictorial representation of a temporary shelter, a transitional shelter and permanent housing. Source: Adapted from (Beatini, Rajanayagam, and Pologanathan 2022).

2.2. Method

The methodology integrates inductive (problem identification) and deductive (solution development) phases, applied in parallel (Figure 2). The inductive phase comprises *stakeholder insights*, which analyses design visions, constraints, and processes promoted by funding agencies; to this follow *design requirements* and their metrics, as outlined by agencies guidelines. *design strategies* are visualized through a case study analysis. In line with the prior Grounded Theory Analysis (Beatini et al. 2022), which revealed causal links between structural challenges and sustainability goals, the structural design solutions of the two case studies are evaluated through a sustainability framework (Institutional sustainability, Environmental performances, Socio-cultural adequacy and Economic effectiveness). In the deductive phase, we elaborate *design principles* that respond to those criteria. We eventually propose a *concept implementation* into a novel structural design concept for transitional shelters, informed by case study insights. Finally, the *concept validation* action reviews the concept against real-world complexity. This iterative approach prioritizes adaptability, ensuring solutions evolve through feedback between problem identification and implementation.

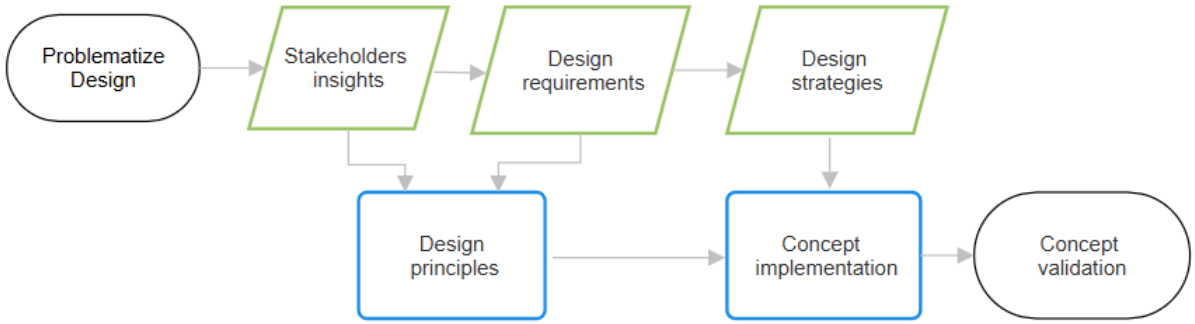


Figure 2: Diagram of the method employed to conceptualize an innovative shelter structural solution. Source: (Authors 2024)

3.0 SETTING A DESIGN FRAMEWORK

3.1. Design brief and process

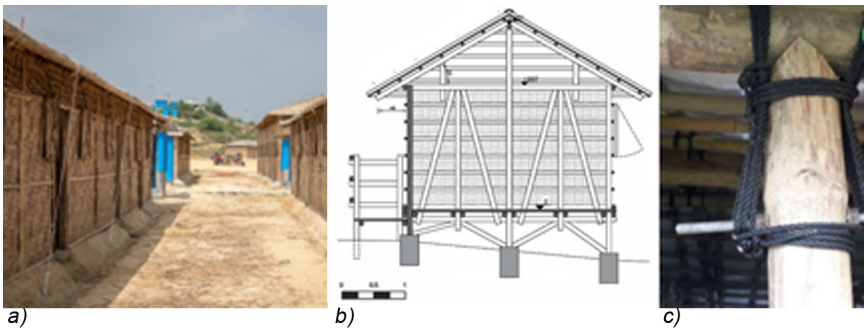
A robust design framework shall start from understanding the needs and vision of the client. The Shelter Centre, a prominent humanitarian NGO based in Switzerland and backed by the UN's International Organization for Migration (IOM), has established a set of guidelines intended for a diverse audience that includes beneficiaries, government task forces, coordinating and implementing agencies, and donors (Corsellis 2012). Accordingly, transitional shelters shall be affordable and economically sustainable, supporting the beneficiaries to restore their income. The shelters shall not only be habitable but also serve as a potential economic resource. The shelter should be adaptable for recycling, upgrading, repurposing, selling to generate income, or transferring from a temporary to a permanent site. Recommendations include sourcing materials locally to benefit the local economy and leveraging culturally familiar technologies to facilitate reselling or other intended uses. Community involvement is critical to ensuring shelters meet local needs and remain economically viable post-deployment (Kennedy et al. 2008). However, the document does not discuss in detail how after usage choices affect the design process and priorities. In terms of the design

process, funding agencies often favour incremental solutions with short-term, quantifiable impacts (Gray and Bayley 2015). To counteract potential stifling of innovation, the Shelter Centre released a draft of Transitional Shelters Prototypes in 2014, encouraging participation from international manufacturers. This draft proposed a transitional shelter that could evolve from plastic sheeting to sustainable local materials with a lifespan of two to five years. Unlike earlier guidelines, it emphasized the shelter's transportability, focusing on total weight and packaging size, without mentioning the usage of local materials at that juncture.

In conclusion, the design briefs and guidelines promote a sustainable economic model for transitional shelters, but there are significant challenges particularly in maximizing the shelter's value towards the end of its lifecycle. Engaging the affected community in the design process could help ensure that the shelter retains its value; however, this might result in unpredictable outcomes. On the other hand, outsourcing solutions guarantees quality but may compromise the overarching goal of enhancing the resilience of the beneficiaries. These dilemmas highlight the complex balance between maintaining control over design quality and involving the community to ensure the shelter's long-term sustainability and relevance.

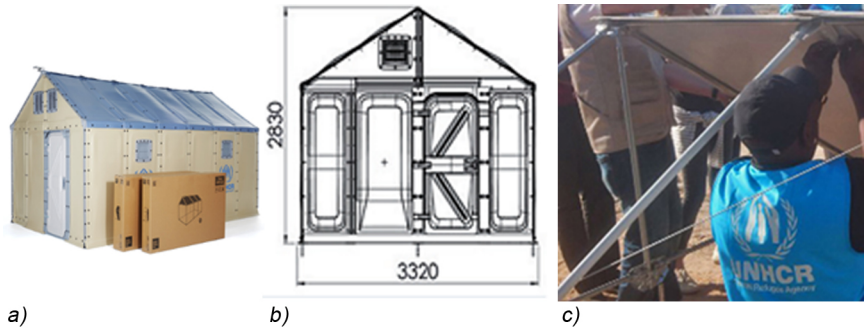
3.2. Design requirements

Establishing design requirements for transitional shelters is inherently challenging due to uncertain deployment scenarios and limited contextual knowledge. Agencies like UNHCR have developed sustainability frameworks to evaluate shelters across environmental, economic, socio-cultural, and technical criteria (UNHCR 2021). A shelter's merit often hinges on its adaptability to changing conditions and its capacity to mitigate risks, highlighting the tension between outsourced solutions (standardized quality) and local manufacturing (situational responsiveness). Structural performance, for instance, is assessed by categorizing failure risks (high, medium, low) to determine context-specific thresholds.



a) b) c)

Figure 3: Bangladesh 2019–2020 / Rohingya Crisis. (a) The constructed shelter. (b) section drawings (UNHCR 2021) (c) Details of a roof joint. Source (all images): (Global ShelterCluster. 2021).



a) b) c)

Figure 4: Refugee Housing Unit (RHU). (a) the constructed shelter Source: (UNHCR Shelter and Settlement Section 2024). (b) section drawings. Source: (UNHCR Shelter and Settlement Section 2023). (c) construction details of a roof joint. Source: (UNHCR Shelter and Settlement Section 2024).

3.3. Design strategies

Two design strategies emerge, outsourced and locally sourced shelters, which significantly affect design decisions. To visually articulate the nexus between design strategies and implementation, two shelters are presented that exemplify these strategies. While both approaches prioritize recyclable and/or biodegradable materials and have proven effective in the field, their design processes differ starkly.

- On-site manufactured shelter (Figure 3): bamboo-steel shelters used in the Rohingya Crisis (2017–present), iteratively improved towards permanent dwelling. Features include biodegradable materials (bamboo framing and panelling), steel joints, hipped roof with gutter, flood-resistant geotextile/sandbags, and a concrete plinth with polythene damp barriers (Shelter Cluster 2020; UNHCR 2021).
- Outsourced shelter (Figure 4): Prefabricated Refugee Housing Units (RHUs) developed by UNHCR and Better Shelter with support from the IKEA Foundation, subjected to large testing before full scale implementation, in line with the Prototype Design Guidelines Designed for transportability and upgradability, it features recyclable steel frames stiffened by steel cross wires, polymer panels, and heat-reflective aluminium roofs with options for installing solar panels (UNHCR Shelter and Settlement Section 2023) (UNHCR Shelter and Settlement Section 2024).

3.4. Case study analysis

The two shelters are analysed across four dimensions: Institutional Sustainability, Environmental Performance, Socio-Cultural Adequacy, and Economic Effectiveness.

Institutional sustainability. Onsite shelters face risks from material repurposing (e.g., here, bamboo bracing was felt not necessary and diverted to other means, which required redesign with steel ropes). Fool-proof designs have are recommended, such as corner half-steel columns and diagonal timber bracings (Portieles 2021; O'Brien and Carrasco 2021), which are less likely to be repurposed. Inadequate local material testing has also been reported elsewhere (Beatini, Rajanayagam, and Pologanathan 2022).

In terms of hazard adaptation, both designs include flood protection, offsite solutions offer traceable fire-resistant materials, but fire safety remains critical—spatial constraints and infrastructure gaps exacerbate wildfire/vandalism risks. A 2020 fire necessitated dismantling and rebuilding the onsite shelter (Shelter Cluster 2020), underscoring economic impact. Shelters' foundations are also highly impacted by the common lack of land rights: adaptable footings allow easy removal, but prefabricated shelters struggle on uneven terrain, requiring ground anchors or concrete slabs (Terne 2022).

Environmental performances. The use of bamboo in the locally sourced shelter notably offers a lower carbon footprint. However, while bamboo was an appropriate choice in this context due to its abundance in the region and rapid growth rate, agencies have raised concerns about the broader use of local materials: a high risk of contributing to deforestation has been reported when timber is used indiscriminately, and masonry construction carries landslide risks. The long-term performances hinges on proper construction, installation, and ongoing maintenance. In the case of the bamboo shelter, detailed attention to joinery was crucial to prevent moisture penetration, leveraging local traditional knowledge (see Figure 2c). This sophistication in design is expected to encourage effective maintenance practices. A bamboo treatment facility was also installed nearby that benefits the local population and enhances material quality. Conversely, the outsourced shelter, while benefiting from simpler installation processes explained through video tutorials, may face more complex maintenance challenges due to its industrialized production methods. Over time, the intention is to phase out the initial shelter's shell, which has limited durability, in favour of more sustainable local materials.

Socio-cultural adequacy. Involving local contractors fosters community benefits, such as reviving traditional techniques (e.g., bamboo construction) and enhancing local economies. Success hinges not on local materials alone but on aligning technology with local capabilities. For example, post-2018 Indonesia earthquake shelters combined light gauge steel frames and silica boards with locally produced concrete blocks, building local processing and installation skills (Global Shelter Cluster 2021).

Psychological well-being depends on features like privacy and sturdy walls/floors, which both approaches address. Cultural adequacy may extend beyond performances (Caia, Ventimiglia, and Maass 2010): internationally procured solutions are typically favoured if they appear well cared, reliable, and aesthetically pleasing. Conversely, local techniques might be viewed unfavourably if they are not widely adopted internationally. On the contrary, in terms of design inclusivity, locally sourced shelters allow customization (e.g., mezzanine additions). Conversely, outsourced shelters prioritize standardized designs, which may led to limited or "artificial" personalization.

Economic effectiveness. Delivery time and spike of material costs during emergencies are typical economic challenges. For the cases at hand, the RHU shelter has a unit cost of $2,156 for 17.5 m² and a lifespan of up to 3 years without upgrades, resulting in a total cost of $22.6 USD/y/m². The cost could lower significantly for the upgraded versions, but field or test data has not yet been published. The locally manufactured shelter costs $1,465 for the same area and boasts an expected lifespan of 10 years, bringing the cost down to $8.4 USD/y/m².
The RHU is packed in two 160 kg boxes, which fit a pellet, and assembled in 4–6 hours by two trained workers. The local shelter has Long bamboo poles transported via river, assembled in 8 days by one skilled and two unskilled workers. Celentano et al. (2019) notes that incorporating 10% - 20% imported elements within a construction technology optimally balances speed and cost, particularly for roofing.

In conclusion, while both shelters address key challenges (Figure 5), trade-offs persist:
- Outsourced: Higher costs if not used for an extended period, but rapid deployment and standardized quality.
- Local: Lower long-term costs but reliant on community involvement and constant monitoring and funding.

Cultural adequacy and environmental performance remain tied to durability, with neither approach universally superior when all factors are weighted equally.

	Institutional Sustainability				Environmental Performance			Socio-Cultural Adequacy			Economic Effectiveness	
Shelter	Structural Standards	Fire Safety	Resilience to Local Hazard	Land Rights	Carbon Footprint	Reliability of Performance	Natural resources	Local Income	Inclusive Housing	Cultural Adequacy	Affordability	Delivery Time
Locally manufactured	●●	●	●●●	●●●	●●●	●●	●●	●●●	●●	●●●	●●●	●●
Outsourced	●●●	●●●	●●●	●●●	●	●●●	●●	●	●●	●	●●	●●●

Figure 5: Visual articulation of the nexus between the challenges and potential design strategies. Source: (Authors 2024)

4.0. NOVEL STRUCTURAL CONCEPT

4.1. Design principles for sustainable emergency shelters

Section 3 has highlighted how the interlaced challenges situate the design for emergencies in the broader realm of sustainable design. Building on this foundation, the following design criteria are proposed, that aim to contribute situating emergency shelters within the global sustainability goals.

- Local Economic Integration: Utilize locally sourced materials to stimulate the local economy and involve local contractors to foster community engagement.
- Health and Safety Standards: Ensure safe and healthy living conditions through high construction quality, adaptable to local construction practices.
- Contextualized Innovation: Develop solutions that combine outsourced elements in the measure appropriate to enhance local resources and ensure adequate performances.
- Technology Utilization: Leverage local carpentry, woodworking, or available skills, supporting existing production and testing facilities.
- Performance Improvement: Implement re-engineering processes of existing technologies, to enhance structural performance and adapt to ongoing technological advancements.

4.2. Composite timber-steel modular building system

Material selection. A range of locally available construction materials have been identified in various studies that do not rely on heavy manufacturing capabilities. These include stone, timber, laterite, clay, mud, bamboo, but also sustainable aggregate potentially reinforced via natural fibres such as sisal and jute (Mathur 2006). However, materials that require complex processing are more difficult to be implemented due to a lack of knowledge on maintenance of required machinery, and inability to produce the material at large scale (Dosumu and Aigbavboa 2019). Recycling of heavy material like greener concrete requires supportive policies which tend to lack even in more developed countries (Kota and Rama 2021). Disregarding novel composites thereof, here, it is chosen to investigate a possible timber structural system.

System Selection. Three possible structural systems have been considered to ensure adaptability and fast deployment amidst logistic uncertainties: deployable – foldable units, modular load bearing panels, and dry - connected linear elements, Figure 6. The last concept is preferred, aligning with design for disassembly principles, it offers significant flexibility for future modifications and mitigates risks associated with logistical constraints (Rajanayagam et al. 2024). While it presents a larger number of onsite connections compared to deployable units, it offers larger adaptability to post emergency scenarios and is less reliant on outsourced, special components. Structural panels, while reliant either on local or outsourced materials, provide the least logistic flexibility and are therefore disregarded.

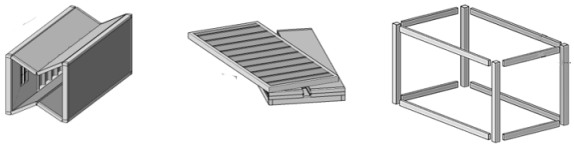


Figure 6: Alternative concepts of structural systems: from left to right, horizontal foldable, vertical foldable, demountable panels, and demountable frame. Source: (Authors 2024)

*Structural requirements***.** Structural reliability must be ensured under both expected and unexpected conditions. Lightweight components are crucial for manual handling. To mediate between these constraints, it is proposed to use composite steel-timber beams and columns. Referring to Figure 7, which compares the specific strength and specific stiffness of timber and steel, steel offers excellent strength and stiffness, but it is heavy, whereas timber provides notable strength and stiffness relative to its density. This composite action allows the two materials to function as a single structural unit, maximizing the benefits of both. Composite timber – steel elements have already been proposed to leverage the environmental benefits of timber and the structural reservoir of steel (Chen et al. 2024). Here, special attention is given to timber's stiffness and the potential for local buckling in steel. Steel C-sections are stabilized against buckling by timber, enabling the use of thinner, cost-effective cold-formed Light Gauge Steel (LGS) sections commonly used in non-emergency small building constructions. The proposed system, hereinafter Timber – Light Gauge Steel (Tim-LGS), is therefore a modular building composed of composite GLS – timber beams and columns.

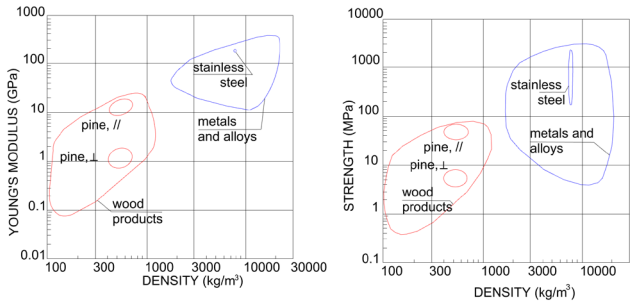


Figure 7: Specific stiffness and specific strength of metals versus timber products, with focus on stainless steel and pine Derived from: (Ansys Granta Materials Data for Simulation). Source: (Authors 2024)

*Principles of Robustness***.** Excessive loads or construction and maintenance errors can lead to sudden and progressive structural failures. The inherent brittleness of timber under tension (see Figure 8) and challenges in transmitting tensile forces at connections often contribute to failures under tensile, bending, and shear stresses. To address these vulnerabilities, robustness principles for structural timber (Sørensen et al. 2011) are implemented, which address the single shelter as a whole, its components, and the design of the single elements. Each modular unit—shelter—is designed to be structurally independent. This compartmentalization strategy enhances flexible site planning and prevents the propagation of local failures, thus boosting overall structural resilience. To resist lateral loads, alternative paths and redundant design are advisable, and here implemented through strategic joint design and the incorporation of shear walls, Figure 10. Ductility is crucial for providing visible warning signs before catastrophic failure. Given timber's lack of ductility (Figure 8) and the potential for steel sections to fail under associated timber failures, ductility is typically achieved at the level of the joint (Čizmar 2014). Enhanced ductility at joints means that large deformations occur due to the deformation of the joint, before the main structural elements fail (Rebouças et al. 2022). Among other means, this can be achieved here by incorporating carefully sized steel fin plates, welded to the columns without significantly impacting transportation volume, Figure 9.

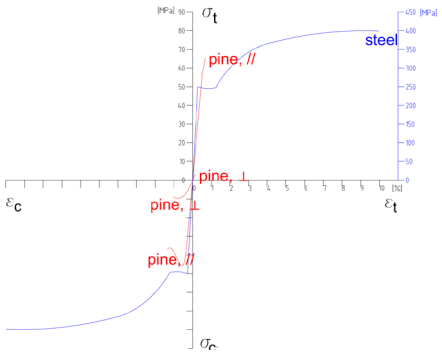


Figure 8: Stress-strain comparison of steel and white pine. Source: Adapted from (Stiemer, et. al. 2012).

Implementation Strategies. The design is relatively simple, but uncommon, therefore, it incorporates foolproof features. It intentionally uses few structural elements and omits bracing ties, which shall not appear redundant even to the inexperienced eye, thus reducing the potential for misuse by end-users. Similarly, the LGS sections shall appear not study enough if used on their own, and the timber elements would require new joints if connected without the LGS.

Schematic design alternatives. The system allows alternative facades design and flooring, key for environmental performances and users' comfort, Figure 10. Similarly, the short span of the roof and the straight beams can meet various roofing technologies. A detailed study may be required in case of pitched roof for snow environments, ensuring that rafters or simple trusses can be easily connected to the timber within the horizontal beams. Uneven terrains require adaptable foundation solutions. Typically, timber elements in small housing are organized in modules with very little span, about 60 cm to 80 cm, which requires numerous anchors to the ground. The proposed solution conversely uses a few columns, which may be integrated with options such as telescopic legs and jacks to provide flexibility and stability.

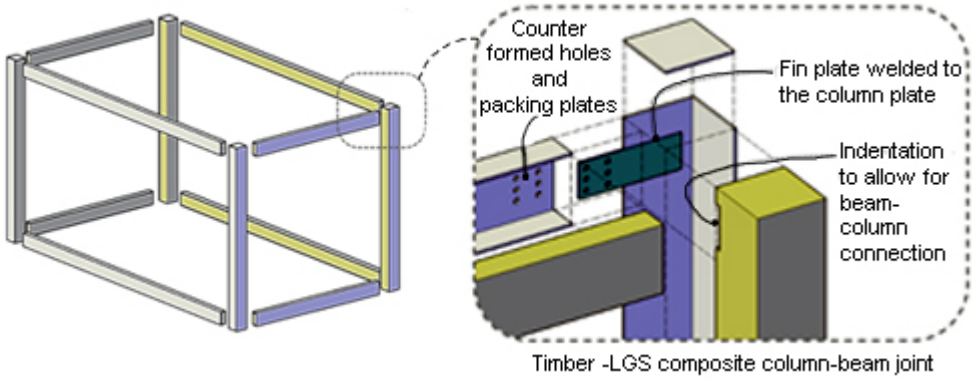


Figure 9: Detailed view of the composite frame of Tim-LGS. Source: (Authors 2024)

4.3. Concept performance analysis

While this study is conceptual, it is critical to assess the quality of the structure concerning integrated design aspects at this stage. As noted by (Corneliusen et al. 2022), modifications made later in the design process may be unfeasible or costly.

Concerning Institutional Sustainability, here lies the core innovation of the Tim-LGS system, which enhances structural integrity while allowing for adaptability to local material properties. This approach not only reduces costs but also tailors the system to varying local timber characteristics.

Concerning socio-cultural adequacy, the design provides ample space for customization, allowing architectural customizations within the overall design framework. Considering the vision of the stakeholders, while the initial investment may be higher than traditional emergency shelter solutions, the long-term benefits are significant, allowing users to adapt, reuse, recycle the elements and material with easy. If the timber elements deteriorate, they may be substituted.

Concerning Environmental Performances, this system uniquely combines the sustainability of timber with the durability of lightweight steel, creating an environmentally friendly solution suitable for emergency scenarios. The potential for recycling and reusing timber and steel components, allowed by the usage of dry connections only, highlights the system's sustainability.

Concerning Economic Effectiveness, the Tim-LGS system benefits significantly from prefabrication, which accelerates the construction process and enhances overall project efficiency. However, the quality of execution, especially in the assembly of joints, is critical for ensuring structural performance. The precision of these joints largely depends on two factors: the correct alignment of the fin plate with the steel elements, and the accurate placement of fasteners. The first step is typically guaranteed through pre-welding but may burden logistic. The placement of fasteners is theoretically straightforward with the help of a blueprint, but the actual installation can still lead to errors or under-joining. These potential issues are present both within the assembly and disassembly phases. To solve them in a viable manner, a strategy is to disassociate the uppermost part of the column from the rest. This approach would allow specifically trained workers to focus solely on the joint assembly, optimizing labour resources and potentially reducing the overall skill requirements for other construction stages. Moreover, the ad hoc joint would not need to be dismantled in case of disassembly.

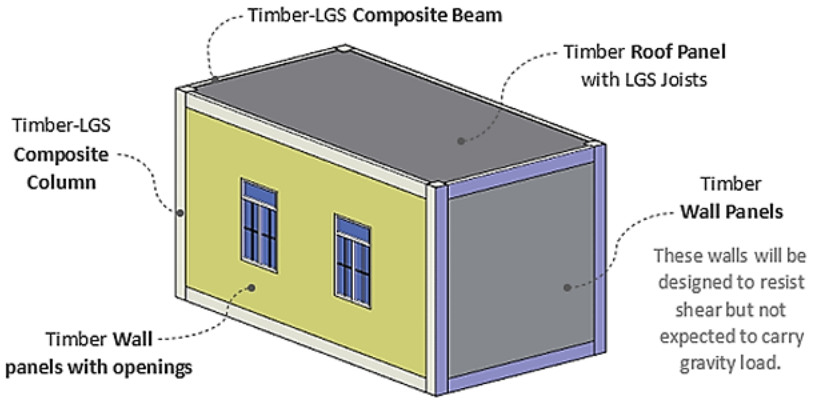


Figure 10: Proposed Tim-LGS Modular Building Unit. Source: (Authors 2024)

CONCLUSION

As the demand for emergency housing surges, this research provides actionable insights and recommendations for developing effective, affordable, and sustainable shelter solutions. Building on previous research, this work advances the understanding of structural challenges in transitional shelters and their interplay with broader socio-economic and environmental issues. By translating these insights into a design framework, we propose the Timber–Light Gauge Steel (Tim-LGS) modular building system, which leverages the composite action of steel and timber to address rapid deployment, cost-effectiveness, and resilience while enhancing sustainability.

The Tim-LGS system represents a multifaceted approach optimized for emergency scenarios but adaptable to broader applications. Its modular design, dry connections, and use of locally available materials offer significant environmental and economic benefits, while its structural robustness ensures reliability in diverse conditions. However, the system's performance, particularly in joint reliability and compatibility with other shelter components, requires further validation through detailed studies. Additionally, contextualized analyses of return on investment and long-term adaptability are needed to fully assess its viability.

This study highlights the potential of innovative, composite material systems to transform emergency shelter provision, moving from short-term relief to sustainable housing solutions. By fostering contextualized research and open debate, this work contributes to the development of design methodologies that address the complex challenges of transitional shelters. Future research should focus on refining the proposed system, exploring its integration with other shelter components, and evaluating its performance in real-world scenarios to ensure its applicability across diverse emergency contexts.

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Manufactured Homes: Accessibility, Resilience, and Enhanced Quality of Life in Three Extreme Climates

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ABSTRACT: This paper asks what can we learn from homeowner modifications of manufactured homes about addressing resilience, accommodation, energy savings, occupation, and flexibility? The authors identify retrofits which decrease heating and/or cooling requirements; provide long term accessibility as owner's age; plan resilience in the face of extreme weather; and enhance quality of life aligned with local culture. Three rural extreme climates in Louisiana, Arizona, and Colorado provide data on a wide range of solutions tailored to the particularities of climate conditions. The resulting assessment identifies categories of modifications and retrofits and associated typologies, for example homes on piers, unconditioned porch or carport additions, conditioned additions, envelope modifications, and changes to provide ADA accessibility.

Quantified assessment through energy and structural modeling evaluates the effectiveness of the homeowner designed retrofits observed in Louisiana, Arizona, and Colorado. The results of assessment reveal that homeowners decreased EUI through simple passive methods adapted from agricultural, aquacultural, and industrial architecture. Energy modeling simulation on case studies for observed retrofit roof assemblies showed up to a 28% decrease in EUI in Louisiana, and 58% decrease in EUI in Arizona. These same retrofits produce large exterior covered occupiable spaces which provide an extended period of thermal comfort by over 20%.

While the paper primarily focuses upon assessment of heating/cooling mitigation through roof assembly retrofit, it also discusses: structural changes through the addition of piers, super structure, and lifting systems along with accessibility and circulation changes, all due to accommodation of FEMA base flood height elevation in Louisiana; window retrofits, window shading, and understory/crawlspace protection and skirting to both provide resilience during climatic events, but also to mitigate heat transfer in manufactured homes in Arizona and Colorado; and heating/cooling source retrofits and augmentation in all three locations.

KEYWORDS: affordable, retrofit, manufactured home, energy modeling

INTRODUCTION

In 1974, the Department of Housing and Urban Development (HUD) began regulating manufactured housing to assure "quality, durability, safety, and affordability." Today, both HUD and the Department of Energy are funneling research funds to the manufactured home industry to design new sustainable homes and to find retrofit solutions to increase energy efficiency and resiliency. Instead of looking to designers or industry leaders, this paper proposes looking at three communities to investigate modifications that homeowners and tradespeople make to their own existing manufactured and modular homes. To produce a range of modifications, this paper investigates homes in rural communities in three different extreme climates.

This paper identifies retrofits which decrease heating and/or cooling requirements; provide long term accessibility as owner's age; planned resilience in the face of extreme weather; and enhanced quality of life aligned with local culture. This includes extensions of unconditioned living space to make it possible to comfortably increase occupancy for extended family members during short-term or long-term living arrangements, or to accommodate rural living patterns. Analysis of these retrofits also reveal decision making based on phased installation, cost control, and designs specific to the particularities of a region's climatic conditions.

This paper asks what can we learn from in situ modifications of manufactured homes from homeowners about addressing resilience, accommodation, energy savings, occupation, and flexibility?

1.0 CONTEXT

Manufactured homes serve a fundamentally important role as affordable housing. Data reveals how that affordability is achieved. Contemporary single wide manufactured homes range in size from about 74 to 130 m2 in floor area, while double wide manufactured homes average 213 m2. (Clayton Homes 2023) Manufactured homes typically have 2 to 3 bedrooms that have an average size of 16 m2 (larger for primary bedroom, smaller for other bedrooms). By contrast, new stick-built homes in 2023 averaged 232 m2 in floor area, with bedrooms averaging 21 m2. 2.5

people reside in the average home (Korhonen 2023). Manufactured homes typically have between 2 and 3 bedrooms, a distribution that aligns with the average occupancy count; in contrast roughly 80% of new stick-built homes have three or four bedrooms, above the average occupancy. (Wade 2021)

Through calculation, single-wide manufactured home average 45% the floor size of a new stick-built home, and a double-wide manufactured home averages 90% the size. In 2023, manufactured home sales were nearly equally divided between single and double wide, with the result that by inhabitable space, manufactured homes are on average 70% the size of stick-built homes. A single-wide is roughly the same size as an average home in 1920 (which had an average occupancy rate of 4.3 people), while today a contemporary stick-built home is 230% the size of an average 1920 home. Stick-built homes in the United States average over 200% the size of European and Canadian housing. (World Population Review 2024)

Manufactured homes cost less to build than stick-built homes per square meter. Labor costs are more stable, since construction is inside and not subject to vagaries of weather. Engineered construction processes limit excess unused materials. Manufactured homes do not contend with costs associated with slab or foundation work. Manufactured homes also favor cost efficient 2x4 construction with limited insulation. The contemporary construction cost of stick-built homes averages $2700/m2 (Grupa 2023) while manufactured homes average $754/m2 (Hazen 2023), though hidden costs like delivery, site preparation, and structural support are additional for manufactured homes.

Both stick-built homes and manufactured homes average energy costs of approximately $180/month. (DOE 2022) (Durani 2023) It is here where an inefficiency for manufactured homes becomes apparent. With the smaller building footprint, this means manufactured home energy costs may be as much as 50% more than stick-built homes. One source of explanation may be the thinness of the envelope assembly and minimal insulation.

With a focus on affordable housing, home equity not only speaks about the value of a home but access to home ownership across the entire population. Manufactured homes are important to rural America, providing the convenience of delivery in lieu of onsite construction. Manufactured homes serve populations disproportionately threatened by environmental disasters due to affordable land ownership in areas adjacent to coasts and in low-lying areas.

Increasingly federal agencies like HUD, USDA, and DOE are investing in manufactured homes as an important way to provide affordable housing for the US populace. These agencies also are steadily supporting new strategies for retrofitting existing manufactured homes, largely driven through engineering solutions developed by building science researchers and industry. The authors feel it is important to also investigate solutions designed by homeowners, analyzing affordable, effective, and easily managed remedies that are tailored to the specificity of local climate and associated cultural awareness.

2.0 FIELD STUDY AND DATA COLLECTION

The authors selected locations in three rural extreme climates to collect information on a wide range of solutions tailored to the particularities of climate conditions. Data from this field study revealed modifications by homeowners that align with agricultural, aquacultural, or industrial building practices common to rural locations, with corresponding material, structural, and detail selection. Unlike tight fit or optimized architecture, these design modifications rely on loose coupling and layering to provide resilience, protection, and flexibility of intended use. Additionally, solutions are often low tech, give preference to passive systems, and may have a sacrificial layer. The solutions provide the capability for mechanically trained self-reliant homeowners or community members to install and repair, rather than relying upon outside technicians who are less available in these underpopulated locations. In some cases, this means highly regionalized solutions appear, differing from one community to the next, based on localized experience and knowledge, including experience gained from local employers. Modifications may exhibit phasing, and the utilization of applications and technologies for other industries being converted to provide the same utility in service to the manufactured home.

Documentation of these modifications provides a taxonomy of solutions that could be utilized in less harsh environments, or in more populated areas, or as a basis for kits that could be purchased by homeowners, for DIY installation.

2.1. Case study 1: Louisiana

Vermillion and Cameron Parishes, along the south Louisiana coast contain small communities like Erath, Delcambre, and Pecan Island. In the face of climate change and due to federal regulation, manufactured homes have been raised an entire floor height to protect from coastal flooding and tidal surge during hurricanes. Lafayette, the closest metropolis is between 30 and 60 miles from these communities. A second site, in Catahoula Parish, is Larto Lake, a remnant oxbow lake from the Red River, that is now fed by the Red River's flooding. To prevent seasonal flooding, many homes are raised a full story above ground. These homes often have extended porch and balcony systems similar in typology to additions witnessed in Vermillion and Cameron Parishes. Alexandria, the

closest city, is 45 miles away. While Larto Lake is inland far enough that it is not susceptible to hurricane force winds, it does have the same hot humid climate as the Vermillion and Cameron Parish sites, absent the cooling breezes from the coast.

2.2. Case study 2: Colorado

Cooperativa Nueva Union is in Leadville, Colorado, the highest incorporated city in the country (10,158 ft). This manufactured home community recently benefited from Colorado's HB20-1201 law, purchasing the park's land from its long-term owner. Temperatures average in the teens for winter months, with typically ten feet of snow fall each Winter and Spring. Modifications consider snow load, extreme cold, and wind. Homes have had multiple owners and modifications are incremental. Denver, the closest metropolis, is 100 miles away.

2.3. Case study 3: Arizona

Roosevelt Lakeview Mobile Home Park is located near Phoenix, on Forest Service Property. The homes were first purchased for tradesmen who were resurfacing one of the world's highest masonry dams with concrete; today, the park is mainly used for summer part-time residency. In 2012, after an intensive fight, the Forest Service agreed to renew the park's long-term lease based upon a plan that included specific rules for retrofit and modification of homes. These rules govern retrofits, including carport construction, standardized window shading techniques, skirting details, utility use requirements, and landscaping regulations. Temperatures average above 100 degrees three months per year, and average rainfall is sixteen inches. Phoenix, the closest metropolis is 106 miles away.

3.0 ASSESSMENT PROCESS

The assessment of data followed a mix of qualitative and quantitative processes. The authors first selected three locations that described extreme climates in the United States: humid, sub-tropical; hot, semi-arid; alpine subarctic. The authors surveyed rural locations to find communities of manufactured homes that had been retrofitted to adapt to the local climate, including documenting communities near to each other but exhibiting differing adaptation methods. Once selected, the authors documented the homes through photography and some owner interviews.

The authors entered the next phase of assessment, identifying categories of modifications and retrofits and associated typologies, for example home on piers, unconditioned additions – porch or carport, or conditioned additions, envelope modifications, and changes to increase accessibility. Categories of retrofit primarily addressed energy cost savings, resiliency / hardening, and accessibility / occupancy accommodation. The authors then reframed the research to look at corresponding elements within the retrofits, so that they could be isolated for analysis:

- Roofs, porches, decks, and carport (unconditioned, covered space)
- Piers, super structure, and lifting systems (structural changes)
- Accessibility, circulation, and conveyance (accessibility)
- Wall assembly and exterior cladding (envelope)
- Window retrofits and window shading (envelope – glazing)
- Understory/crawlspace, underfloor membrane, and skirting
- Heating/cooling source retrofit or addition

This paper qualitatively describes the retrofit innovations that the authors found for each element in the subcategories, and how the homeowners address climate while also aligning with cultural identity and accommodation. To develop a method for quantitative analysis, the authors selected one manufactured home case study in Louisiana and in Arizona to study roof, porch deck, and carport condition as an initial test of analysis method. To evaluate effectiveness the authors and their graduate assistants constructed digital models in Revit, and then the authors analyzed the models in DesignBuilder in conjunction with thermal comfort analysis for the sites. The resulting data is presented below. It identifies innovations, misconceptions, and opportunities for improvement.

As mentioned earlier in this paper, the energy consumption of manufactured homes is higher compared to single-family homes primarily due to inadequate insulation and the use of materials that are not suitable for different climates. In Arizona, the average Energy Use Intensity (EUI) number for manufactured homes is 104 kWh/m2 while in Louisiana, it is 70 kWh/m2. These numbers are significantly higher than the EUI values for single-family homes. For single-family homes in Arizona, the EUI ranges between 38-73kWh/m2, and in Louisiana, it ranges from 63-73 kWh/m2 based on home wall structure (NREL 2024). To investigate the impact of certain modifications on energy consumption and EUI numbers in manufactured homes, a building energy simulation was conducted using DesignBuilder for both the Louisiana and Arizona locations.

In the next phase of research, the authors plan to return to the communities, further identify stakeholders, and complete additional surveys at the scale of analysis of retrofits to envelope assembly bolstered by forensics. With this additional data, the authors will refine digital models and corresponding energy analysis, while adding structural analysis. A future stage of research envisions developing a program that identifies test homes, placing sensors and collecting utility information, to compare homes that have not been modified with those that have. This added layer

of information will be used to validate the data generated from the energy modeling. The authors observed non-modified similar homes in each location, allowing for comparison of data.

3.1. Roofs, porches, decks, and carport

In the two hot climates of Louisiana and Arizona this study identified many added roof configurations hovering above the manufactured home's original roof, and the corresponding heat absorption and transfer. (fig 1 & 2)
In Louisiana, typically these roofs were positioned 9-12 inches above the existing roof, supported by either wood or steel beams and rafters, clad with metal deck but without a layer of OSB or plywood sheathing. Open air circulates between the two roof layers, and the original asphaltic roof is protected from sun and extreme heat degradation and leaks. The construction methods of these roofs ally with agricultural and aquacultural building methods of barn and shed construction. It could be argued that the principles also follow that of contemporary rain screens in commercial architecture, with the added benefit of providing air circulation at the building's hottest location.

In Arizona, the authors again witnessed adding metal roofs on top of the asphaltic shingles, but in this case the space between roofs is smaller than witnessed in Louisiana, and gables close off the space between the metal roof and the original manufactured home roof, creating a liminal attic space. The author's also noted extension of the roofs to create large carports and spraying white polyurethane insulating foam onto the metal standing seam which covers the asphaltic shingles.

Quantified results of energy modeling simulation conducted for Louisiana indicate that adding a metal roof over the asphalt roof can bring down the EUI number by around 13%, reducing it from 101 kWh/m2 to 88 kWh/m2. Introducing a 12-inch air cavity between the two roofs can lead to an additional 15% reduction, bringing the EUI number down to 75 kWh/m2. A similar study conducted in Arizona showed that adding a metal roof over the asphalt roof can reduce the EUI number by 30%, lowering it from 130 kWh/m2 to 100 kWh/m2. Additionally, the inclusion of a 4-inch polyurethane foam insulation on top of the metal can reduce the EUI number by another 28%, taking it down from 100 kWh/m2 to 73 kWh/m2.

In addition, extending the roofs to cover the carport area also impacted energy consumption in the study. In Louisiana, this modification resulted in a 2% reduction in annual energy consumption, while in Arizona, it led to a 5% reduction. By extending the thermal comfort zone for occupants, the larger roof can contribute to a more comfortable indoor environment, potentially reducing the need for excessive cooling and improving overall energy efficiency.

Roof material selection and color further yield temperature reduction, with a corresponding heat load reduction for HVAC in conditioned space. Conventional roofs can reach temperatures of 65°C or more on a sunny summer afternoon. Under the same conditions a reflective roof could stay more than 28 °C cooler (US Department of Energy 2023). Solar reflectance from a cool roof in air-conditioned residential buildings can reduce peak cooling demand by 11–27% (US EPA 2014). Additionally, an efficient total roof system can lower the energy required for cooling a Louisiana home by 30 percent or more (Davison, Heinberg, and Williamson 2010). While metal roofs may cost $108 sq/m (ASHI 2023), which is double in price compared to asphalt roofs, they are long lasting, needing replacement after 40-80 years in comparison to asphaltic roof replacement every 15 years in the hot climates of Arizona and Louisiana. To further evaluate this comparison, the team will calculate LCA of the standing seam with rolled asphaltic shingles in the next phase of research to relate purchase cost with overall environmental cost.

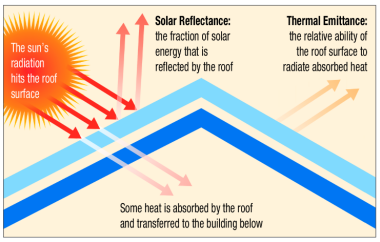


Figure 1: Solar reflectance, thermal emittance, heat absorption and transfer from solar radiation interacting with the surface of a roof. Source: (Mohan Rawat, R.N. Singh 2022)

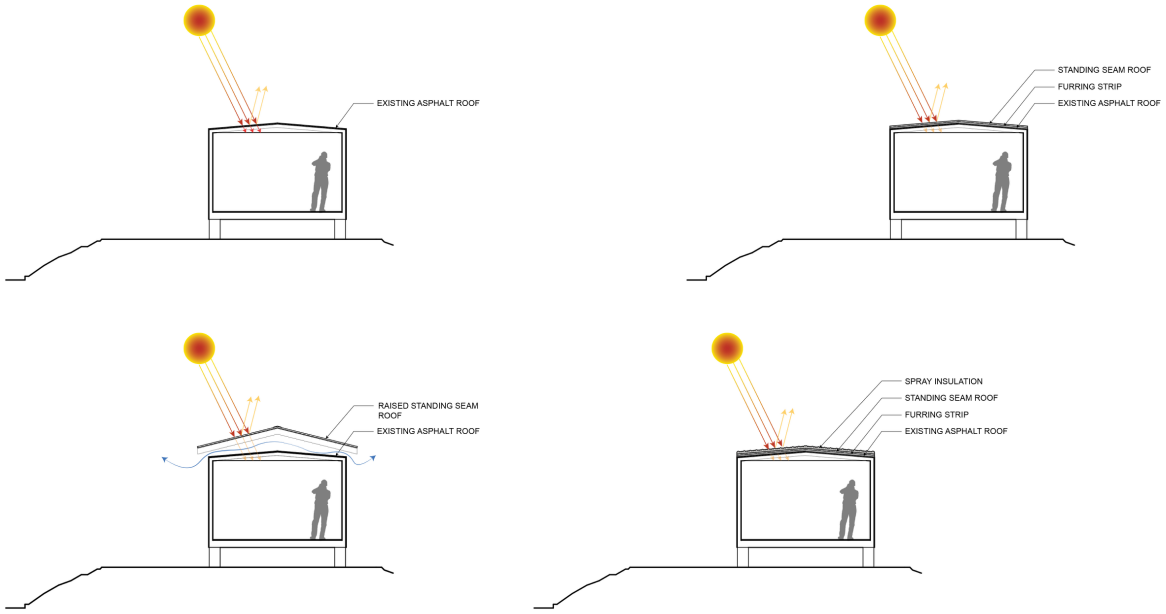
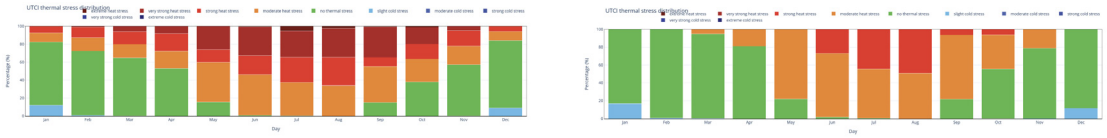


Figure 2: Solar reflectance, thermal emittance, heat absorption and transfer from solar radiation interacting with the surface of a roof for four conditions: asphaltic roof, LA and AZ; standing seam metal roof installed on top of asphaltic roof, LA and AZ; standing seam metal roof with .3-meter air gap, LA; standing seam metal roof installed on top of asphaltic roof with additional .1 m of white spray foam insulation on top of standing seam. Source: (Authors 2024)

It is important to note that the extended roof can provide additional benefits beyond energy consumption. One of these benefits is the increased shading area, which can enlarge the occupiable outdoor environment to incorporate unconditioned porches and carports. With manufactured homes providing on average 30% less conditioned living space than stick-built homes, these covered, unconditioned spaces deliver extended living space for a large part of the year in Louisiana and Arizona. Of the attached porches we observed usable square footage increased by at least 50%.

In Louisiana, residents' experience uncovered thermal comfort 8% of the year, predominantly during September, and October with an average of 3 months (Dec to Feb) of temperature below thermal comfort during the year. During the warmer months, residents experience uncovered thermal comfort as low as 2% in Jun and 0% for July and Aug for activities during waking hours. Covering a porch, while allowing cooling breezes through screens lengthens external thermal comfort by 20%, specifically during morning and early evening hours. Ceiling fans provide an additional 10% thermal comfort during this same period. Additionally, porch spaces are sheltered from rain, and often screened to provide protection from insects. (fig 3 & 4)



a) b)

Figure 3: Thermal Stress distribution for outdoor thermal comfort in Louisiana, a) with sun and no wind b) with no sun and no wind. Source: (Betti 2003).

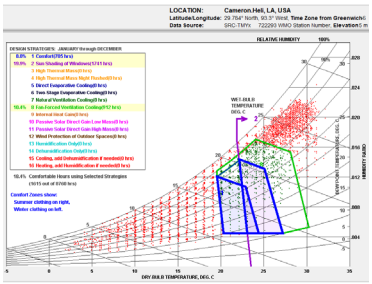
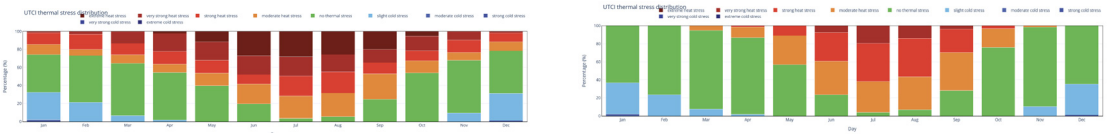


Figure 4: Psychometric Chart for Louisiana thermal comfort zone and best strategies to expand the comfort zone. Source: (UCLA Energy Design Tools Group 2019).

In Arizona's hot dry climate, thermal comfort is also extended through porches and carports. Uncovered thermal comfort for Arizona is 10% throughout the year, with an average of 5 months (Jan to March, Nov, and Dec) of temperature below thermal comfort. During the warmer months, such as July, residents experience uncovered

thermal comfort only for 3.5% compared to October with 30%. Covering a porch, while allowing cooling breezes through screens lengthens external thermal comfort by 23%, specifically during morning and early evening hours in the summer. For example, shading strategies can expand the comfort level from 3.5% to 42% in July. (fig 5 & 6)



a) b)

Figure 5: Thermal Stress distribution for outdoor thermal comfort in Arizona, a) with sun and no wind b) with no sun and no wind- Source:(Betti 2003).

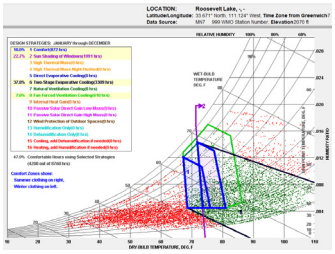


Figure 6: Psychometric Chart for Arizona thermal comfort zone and best strategies to expand the comfort zone- Source: (UCLA Energy Design Tools Group 2019).

These covered spaces also protect homeowners' belongings. The paint lifespan for a car, boat, or four-wheeler parked in the sun is roughly half the length of being protected. As a result, an unconditioned carport significantly extends the value of automobiles and equipment. The authors recognize that shading of porches impacts daylighting. In future calculation iterations, the authors will refine models to consider increase in utility cost to light interior spaces might offset decreases in utility cost due to reduction in solar thermal load.

3.2. Piers, superstructure and lifting systems

In the face of climate change and due to federal regulation, manufactured homes have been raised an entire floor height to protect from coastal flooding and tidal surge during hurricanes in Louisiana, in alignment with FEMA establishing base flood elevation height. In some cases, raising homes or roofs accommodates RV parking beneath the roof, or home itself. Residents have redesigned the areas underneath the manufactured homes to provide dedicated spaces to embrace all facets of Creole and Cajun heritage: cleaning fish and game, working on equipment, and gathering for meals, music, and dancing.

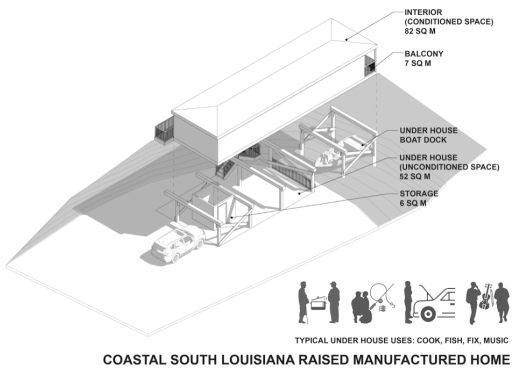
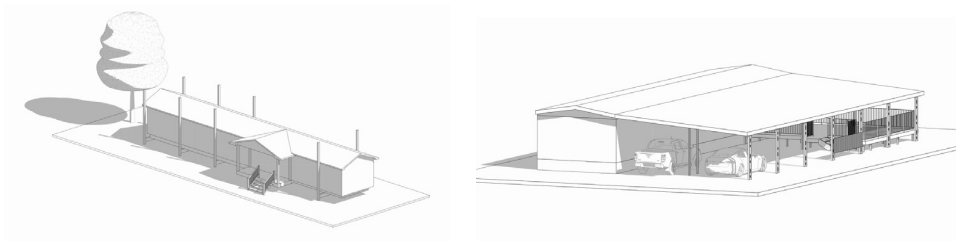


Figure 7: Covered spaces under the manufactured homes are used in culturally relevant ways. Source: (Authors and GAs 2024).

In Cameron and Vermillion Parishes, construction draws from aquacultural architecture using primarily wood piling supporting wood structure clad with uninsulated standing seam roofing. In some cases, piers are reinforced concrete masonry units. Larto Lake, 120 miles north of the coast in Catahoula Parish, contends with seasonal flooding from the Red River. Many houses are also raised a full story above ground. Unlike Vermillion and Cameron parish, all support structure is steel. Several homes have the added capability of being further elevated using a hand winching system, an adaptation of dock winching systems seen along the lake's shore.



a) b)

c) d)

Figure 8: Typologies accommodate climatic conditions and accessibility. a) hand winching system to raise a home above flooding in Louisiana b) extensive carport in Arizona c) home with mechanized lift in Louisiana d) ADA ramp in Louisiana. Source: (Graduate Assistants Salomon Rodriguez, Rachel Helminger 2024).

3.3. Accessibility, circulation, and conveyance

In Cameron and Vermillion Parish, changes to FEMA base flood elevation marks the built environment, as houses built during different decades are built to different heights. Nearly all homes in these flood prone areas are raised to a height that affects ADA accessibility. This is especially relevant as this rural, independent populations tends to prefer to age in place. The authors observed a range of resultant solutions, from electrified lifts to ramping. In Louisiana, wood ramps rot, and algae grows on the surface, making them hazardous. Further investigation will reveal whether the commercial sector is adequately serving this population with products that accommodate the situation while also acknowledging the climatic conditions.

3.4. Wall assembly and exterior cladding

Many of the homes observed retained original vinyl or metal sheathing. Some portion of this siding was covered in mold, algae, or rust. Additional research will focus on where retrofits have occurred. One area of observed solutions is retrofitting exterior wall assemblies to stucco in Colorado. Stucco is seen as a vernacular material, and tradesmen are used to working with it. Given the interest by the DOE on retrofitting with prefabricated panels, analysis of stucco performance could provide useful data on benefits of sealing assembly, and insulative properties of layers within the retrofit assembly.

3.5. Window retrofits and window shading

Window replacement represents a substantial cost. In lieu of this retrofit, the authors witnessed a variety of low-tech passive solutions that decreased heat gain. In Arizona, the authors documented a range of shading interventions, from awnings to louvered partitions, and including some coverings that could also be lowered and locked to provide security when homeowners travel. In Colorado storm windows are extensively used, adding an extra layer of material to prevent air leakage.

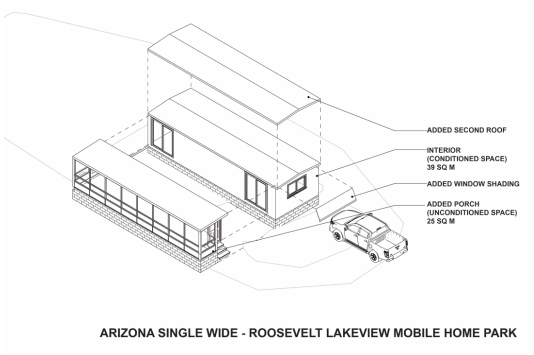


Figure 9: Homeowners have also retrofit skirting systems and added varied methods to decrease heat exchange through windows. Source: (Authors and graduate assistants 2024).

3.6. Understory/crawlspace, underfloor membrane, and skirting

Many observed modifications sought to harden and protect the undercarriage vapor barrier and associated insulation. Homeowners sought a variety of skirting options that attempted to obviate wear and tear, especially plastic skirting that becomes brittle in sunlight, and can be chewed by animals seeking protection which can result in related damage to vapor barrier and insulation. Homeowners also sought to replace the lack of permanence that skirting portrays, often retrofitting with more permanent protective materials. Homeowners seek to deploy sheet

goods to decrease breeze. There also seems to be a perception that skirting with mass, like stone, brick or concrete, provides thermal protection against temperature change. In Arizona, vernacular materials like stone also give the visual perception of connection to the ground, and perceived benefit of using local materials. Unfortunately, DIY solutions are fully sealed, exhibiting a lack of understanding of the need to provide ventilation to prevent condensation and rot. One unique solution was observed in Larto Lake, where clickable metal ceiling planks were installed along the underside of the home, exhibiting ease of installation, flexible access to MEP infrastructure, breathability, while resisting unwanted impact.

3.7. Heating/cooling source retrofit or replacement

Modifications include replacement of and supplementation to original HVAC units. In Louisiana and Arizona, some homeowners replace window units and inefficient HVAC units with mini splits. Manufactured homes' efficient floor plans, in conjunction with the ability to establish zones that can be turned off when unoccupied make mini splits particularly well suited to this housing type. The authors plan to investigate how the addition or retrofit of mini splits affects existing ducting, and if abandoned ducting is being retrofit to decrease heat/cold transmission. In Colorado, the addition of wood burning stoves to offset utility costs, also provides a resiliency solution. The forests are choked with beetle kill pine in Lake County, and burning it is seen as a method to mitigate fire danger in the summer. Finally, when homeowners replace window units there is a corresponding increase in daylighting, and the opportunity for sealing gaps created by the propped windows. In the future, using comparative modeling, the authors plan to evaluate the resulting gains in efficiency.

CONCLUSION

This paper is a first phase of research, documenting homeowner modifications to manufactured homes through photographs, digital modeling, and initial computational analysis. These modifications do not adhere to climate tightened engineered solutions, and yet our calculations reveal they are effective, while being low cost, and easily installed. Phases of research beyond this paper will include homeowner interview, collection of data on utility use, manufactured model # identification and sourcing of original design specifications, further documentation on any specific modifications beyond what was initially observed, with a particular focus on modifications to sealed off crawl spaces, changes to exterior envelope, roof conditions, and/or hvac/mini split retrofits.

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The Energy Storage Capability of Building Rainscreen Cladding Panels Integrated with Photovoltaic and Reversible Proton Exchange Membrane Fuel Cells

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ABSTRACT: This study forms an integral part of an ongoing doctoral project aimed at developing and assessing building skin solutions intended for use as distributed energy sources. Photovoltaics (PV) have become extensively employed and integrated into buildings to harvest solar radiation and produce electricity. However, a notable challenge with photovoltaics lies in their intermittent nature, which leads to an unreliable and unstable energy supply. As more photovoltaics are introduced to the grid, the "duck effect" emerges, exacerbating the difference between maximum and minimum energy supply in a day, posing a threat to power infrastructure stability. Addressing these issues, one strategy involves the use of batteries, although they are constrained by scalability and degradation concerns. A promising alternative for energy storage in buildings is the Reversible Proton Exchange Membrane Fuel Cell (RPEMFC), which, despite being used in power facilities, has not seen widespread adoption in buildings. Our objective is to design building components that can seamlessly integrate a reversible fuel cell with photovoltaics, creating a self-sufficient system capable of providing renewable energy for the building. This paper presents three significant contributions: (a) The proposal of a building cladding panel with the capability to harvest solar energy, convert it into hydrogen for storage, and subsequently utilize the stored hydrogen to generate electricity. (b) Conceptualization of the building system and an illustration of its functionality within a building context. (c) Execution of simulations using Matlab/Simulink to assess the capability of hydrogen production and storage. The simulations were conducted in two distinct locations, namely Phoenix, Arizona, and Chicago, Illinois. The study suggests that optimal outcomes are not achieved in the hottest weather conditions; specifically, the highest hydrogen production occurred in winter due to larger zenith angles hitting vertical building facades and lower temperatures being conducive to PV-RPEMFC performance.

KEYWORDS: Solar energy, Renewable energy storage, Reversible fuel cells, Building integration

INTRODUCTION

Buildings contribute significantly to global fossil-fuel energy consumption and carbon emissions. Embracing renewable energy sources for power generation presents a compelling prospect for achieving net-zero and carbon-zero buildings. Among the various renewable options for sustainable construction, photovoltaic systems have emerged as a leading technology. One significant obstacle for PV systems is the intermittent and unpredictable nature of solar radiation (Yin et al. 2020). To address the intermittent nature of PV energy, the integration of a reliable energy storage system offers a practical and efficient solution (Suberu et al. 2014, 499-514). While numerous examples and practical projects involve PV systems and electrochemical storage solutions like batteries in architectural projects, our study places a special emphasis on a more scalable, versatile, and environmentally friendly technology to be used in building skins: reversible proton exchange membrane fuel cells (RPEMFC), which store energy in the form of hydrogen (Zhang et al. 2023, 2203). In our study, we investigate the integration of PV and RPEMFC systems into building cladding panels and provide a space-efficient solution that could be installed on existing building skins; therefore, utilizing vast areas of urban building surfaces for harnessing and storing energy.

Electrochemical applications permeate various sectors, including industry, transportation, and building infrastructure, serving as pivotal components for both energy storage and production. Three primary genres of electrochemical devices—batteries, supercapacitors, and fuel cells/electrolyzers—constitute the diverse landscape of this technology. Predominantly, batteries stand out as the most prevalent electrochemical applications, with secondary batteries serving as the primary choice for energy storage due to their charging/discharging ability, operational simplicity, and low maintenance requirements. However, challenges such as limited scalability, degradation, and self-discharging are inherent in their design (Kolosnitsyn and Elena 2008, 506-9). The lithium-ion battery emerges as a promising development, boasting high energy density and an extended life cycle (Xu et al. 2018, 1131-40). Flow batteries, while not commonplace in daily life, find utility as grid energy storage devices owing to their impressive scalability (Weber et al. 2011, 1137-64). Another form of electrochemical application is the supercapacitor, with specific building applications having been developed (Andrés et al. 2022, Berestok et al. 2021). An intriguing example is the photocapacitor, a singular device designed to harvest solar energy and store it within

itself. The reported energy density of 1.6 x 10-4 Wh cm-2 and 4.27 Wh cm-2, while relatively low compared to PV-battery systems, underscores its potential. Notably, Vaghasiya et al.'s group (2021) employed 3D-printing technology to transform bricks into a supercapacitor, showcasing an innovative building component that can efficiently store energy.

Fuel cells/electrolyzers, as a distinct group of electrochemical applications, exhibit notable scalability and harness the clean energy storage capabilities of hydrogen. This makes them a viable option for producing and storing energy in a pristine form. Studies on building cogeneration systems, such as those by Ashari et al. (2012), Chahartaghi and Kharkeshi. (2018, 805-17), and Chadly et al. (2021), underscore the versatility and applicability of fuel cells/electrolyzers. Additionally, innovative approaches, such as You et al.'s (2019) development of bricks utilizing urine for electricity production through microbial fuel cells, further showcase the evolving landscape of electrochemical applications.

After an extensive examination of various electrochemical applications, our inclination for advancing building technology centers on the reversible proton exchange membrane fuel cell (RPEMFC). This innovative technology seamlessly integrates the functions of an electrolyzer and a fuel cell, enabling it not only to split water into hydrogen and oxygen but also to convert hydrogen back into electricity. In the prototype developed in this study, instead of utilizing a market available RPEMFC, two cells—a electrolyzer and a fuel cell—were employed to represent the electrochemical conversion process. This choice is justified by the remarkable scalability of the RPEMFC and its ability to store energy in the super-clean form of hydrogen, emitting no CO2 upon combustion. In contrast to other fuel cell types with stringent operational requirements, such as the Solid Oxide Fuel Cell (SOFC) that demands temperatures ranging from 600 to 1000°C, the RPEMFC operates at relatively low temperatures. This characteristic makes it well-suited for ambient conditions commonly encountered in buildings.

1.0 STUDY OBJECTIVES

The primary objective of this investigation is to propose and assess building skin solutions engineered to adeptly capture, transform, and store renewable clean energy through the integration of photovoltaic (PV) technology and reversible proton exchange membrane fuel cells (RPEMFC). Specifically, this study aims to:

(a) Conceptualize and develop prototypes or propose potential designs of building skins cladding with PV-RPEMFC integration. These claddings would be capable of harvesting, converting, and storing solar energy while addressing architectural and safety considerations.
(b) Establish a system that seamlessly integrates these innovative panels into the energy supply and storage infrastructure of entire buildings.
(c) Utilize Matlab/Simulink to simulate the energy efficiency of a building facade incorporating a PV-RPEMFC system. Evaluate the system's hydrogen production capabilities in two distinct climate scenarios and conduct a comparative analysis.

2.0 PV-RPEMFC CLADDING PANEL PROTOTYPE DESIGN AND BUILDING SYSTEM DESCRIPTION

2.1. Preliminary demonstrator

A preliminary prototype has been constructed to elucidate the operational principles of the system. Further details can be found in the initial investigation by Zhang and Azari (2025). The reversible fuel cell utilized in this prototype is capable of functioning as both an electrolyzer and a fuel cell simultaneously. The hydrogen production was measured at approximately 15.7 W/m2, resulting in an energy conversion efficiency of 8.76%. Due to the demonstrator's primary purpose of illustrating system functionality, potential issues such as gas leakage and connection problems may have led to imprecise measurements, rendering the results inconclusive for validating simulation outcomes. A new prototype is currently under development, with our proposed design for a PV-RPEMFC panel outlined in the subsequent section.



Figure 1: A demonstrator of using RPEMFC to store energy. Author: (Zhang and Azari 2025)

2.2 The PV-RPEMFC cladding panel prototype design

The proposed modules are designed to be installed on building surfaces, particularly on facades in urban areas where solar energy can be harvested. The modules can be installed on existing buildings or newly constructed facades. The PV-RPEMFC based cladding units are composed of multiple layers, starting from the outermost layer, which is made up of photovoltaic cells, and followed by RPEM fuel cells (Figure 2). The photovoltaic cells are responsible for harvesting solar radiation and converting it into electricity. This electricity can either be used immediately or converted into chemical energy through PEMFC.

The cladding prototype employs SUNAPEX monocrystalline silicon as the PV panel, with each panel measuring 38 cm in length and 34 cm in width (“Amazon.Com: Sunapex 20W Solar Car Battery Trickle Charger & Maintainer” n.d.). The PV panel operates at 18 V with a maximum power output of 20 W.

For the reversible fuel cell working process representation, an electrolyzer and fuel cell are used. The PV panel is matched with a PEM electrolyzer to convert electricity into hydrogen for energy storage. The chosen electrolyzer from Fuelcellstore (“PEM Water Electrolyzer 1-Cell Stack - Assembled,” n.d.) is a PEM water electrolyzer with a 1-cell stack and an input power range of 10-80 W, suitable for the PV output power. The active area of the PEM water electrolyzer is 25 cm2, generating hydrogen at a rate ranging from 0 to 370 mL/min.

To connect the PEMFC to the photovoltaics, wires are employed, with the anode and cathode connected to the positive and negative sides of the PV cells, respectively. During the initial energy conversion of RPEM fuel cells, hydrogen and oxygen are produced. A solid-H BL-18 metal hydride storage system (“BL-18 Metal Hydride,” n.d.) is utilized for hydrogen storage due to its small volume and significant storage capacity. This metal hydride storage cylinder, around 8 inches in length (slightly longer than a pen), has a storage capacity of 18 liters of hydrogen. The product is known for its safety in storing flammable hydrogen gas. The cylinder's size allows for a slight increase to release hydrogen without the need for a large container and compressor in the traditional hydrogen storage method.

During nighttime when solar energy is unavailable, PEM fuel cells use the stored hydrogen and air to generate electricity. The PEM fuel cell chosen for demonstration is the PEM Flex-Stak Assembled from Fuelcellstore (“Flex-Stak Assembled,” n.d.), featuring a 1-cell stack with an active area of 10 cm2 and a nominal output power ranging from 0.25 to 0.35 W.

The cladding units serve as energy generators, producing electricity through a combination of solar energy harvesting and PEM fuel cell technology. This approach offers a promising solution for sustainable building design and energy generation.

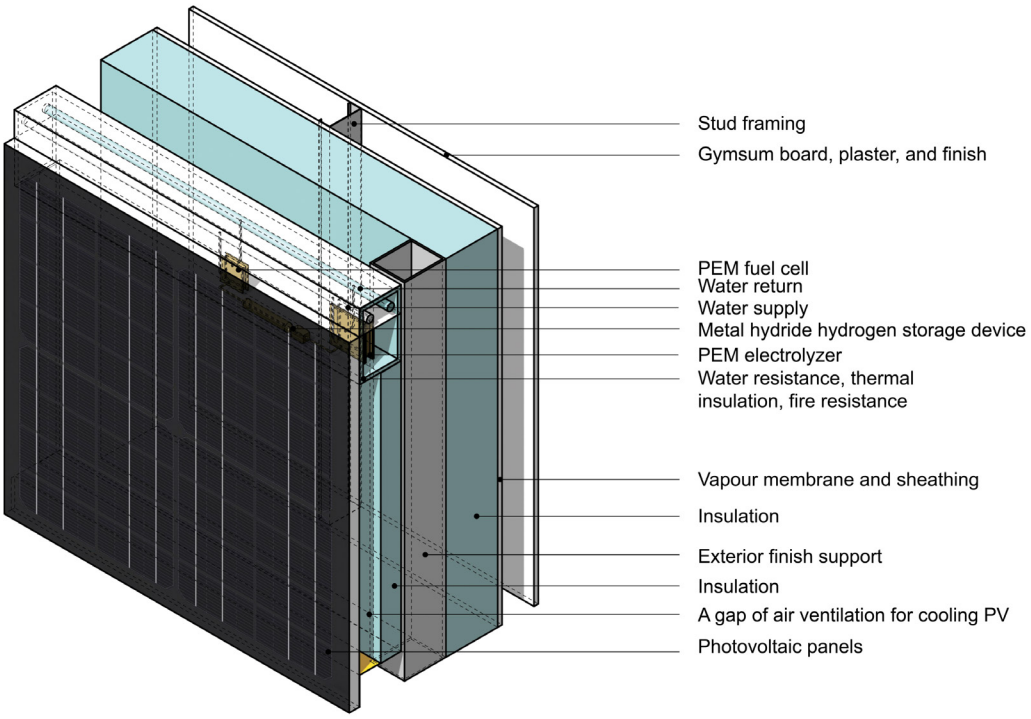


Figure 2: Proposed PV-RPEMFC. The figure shows the conceptual layering of PV-RPEMFC cladding panels, while the functionality is described in the text. Source: (Author 2024)

2.3. Building system description

Cladding panels stand out as a promising application for building skins seamlessly integrated with PV-RPEMFC technology, particularly in urban where large area of surfaces can serve as solar energy receptors. Rain-screen

cladding, typically employed as a protective outer layer for buildings, gains significant value when equipped to harvest solar energy, especially amid today's energy scarcity challenges.

When configuring PV-RPEMFC as cladding panels, adherence to specific codes such as the International Building Code and International Solar Energy Provision becomes imperative. Factors such as weather resistance, water resistance, and fire protection assume critical importance for these components. Safeguarding auxiliary wires and water circulations is essential for safety, addressing concerns such as frost protection in winter and preventing overheating in summer. To address these considerations, we propose a protective channel installed along each row of PV-RPEMFC panels. This channel is designed to be electrically insulated and fire-resistant, eliminating the need for additional hydrogen tanks or compressors, as the hydrogen is already stored within the cladding panels themselves.

In essence, PV-RPEMFC panels serve a dual purpose—they function not only as cladding panels but also as devices for harvesting and storing energy. The generated electricity is subsequently harnessed and conveyed to the buildings for consumption. Installation-wise, these panels are affixed or installed in a manner similar to conventional cladding panels.

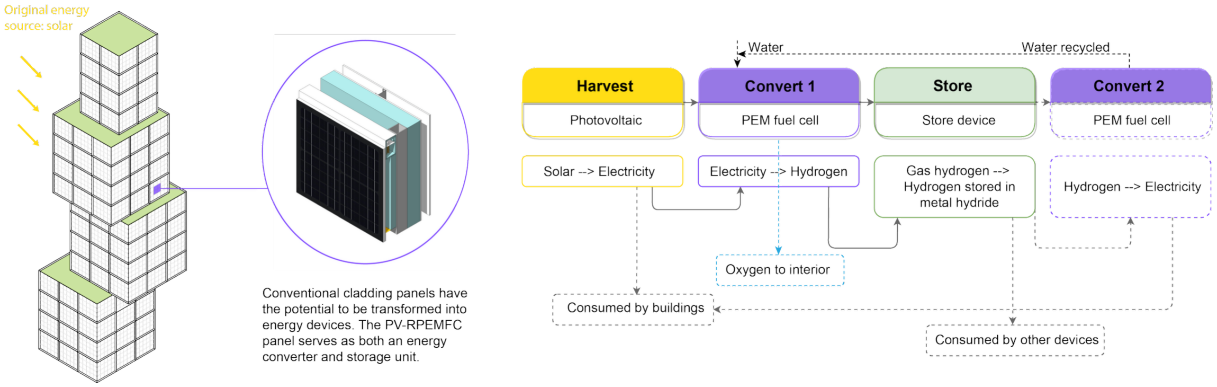


Figure 3: The energy conversions in the PV-RPEMFC system. Source: (Author 2024)

3.0 SIMULATION

3.1. Simulation setup

The simulation utilized the U.S. Department of Energy's prototype residential building model – multi-section electric furnace family (Department of Energy, n.d.). EnerglyPlus weather data EPW locations for Phoenix and Chicago were employed to conduct an EnergyPlus building energy consumption simulation. The energy consumption per conditioned building area was found to be 13.14 kWh/m2 in Phoenix and 18.81 kWh/m2 in Chicago, with a conditioned building area of 1568.72 m2 and a south façade total area of 448.24 m2, including an opaque wall area (non-glazing area for installing PV-RPEMFC panels) of 401.18 m2. It was assumed that 100 square meters of the opaque wall on the south façade would be covered with PV-RPEMFC panels. Subsequently, an energy simulation using Matlab/Simulink was conducted to assess the potential energy contribution from these panels to buildings.

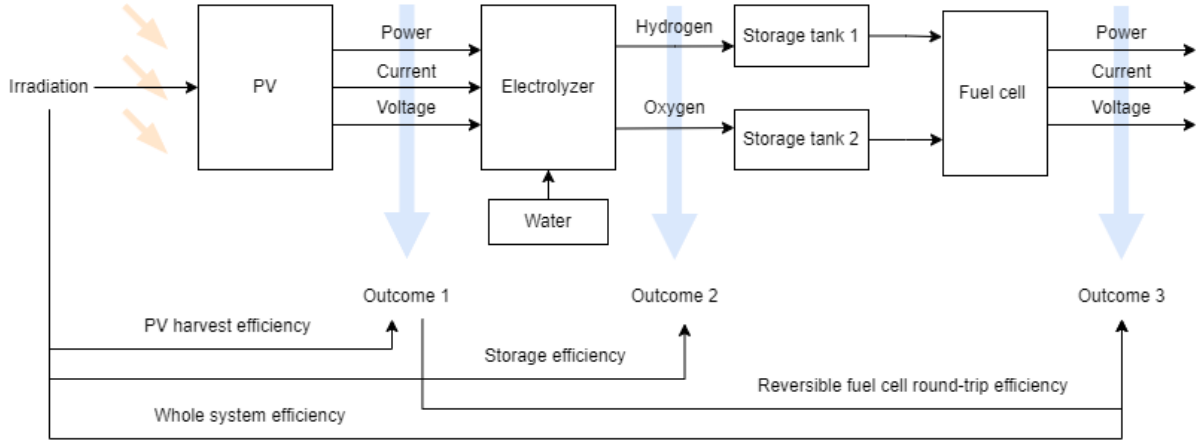


Figure 4: Matlab/Simulink Simulation framework. Source: (Author 2024)

A MATLAB/Simulink diagrammatic model was employed to estimate the energy storage capacity of the system. Leveraging MATLAB's robust mathematical capabilities and Simulink's user-friendly interface for researchers, the primary objective was to gain insights into the performance of energy harvesting, storage, and conversion within

this multi-family residential building context.

The simulation encompassed two distinct climate zones: Chicago, categorized as climate zone 5A (cool humid) (ASHRAE 2020), and Phoenix, classified as climate zone 1B (very hot dry) (ASHRAE 2020). Key inputs for the model included daily irradiation, temperature, wind speed, from EnergyPlus, specifically 'Surface Outside Face Incident Solar Radiation Rate per Area [W/m2] (Hourly)', 'Site Outdoor Air Drybulb Temperature [C] (Hourly)', and 'Site Wind Speed [m/s] (Hourly)'. The energy source, radiation, was directed to the PV module to generate electricity, which was then used to split water and produce hydrogen stored in a tank. The fuel cell later utilized this stored hydrogen to generate electricity once again.

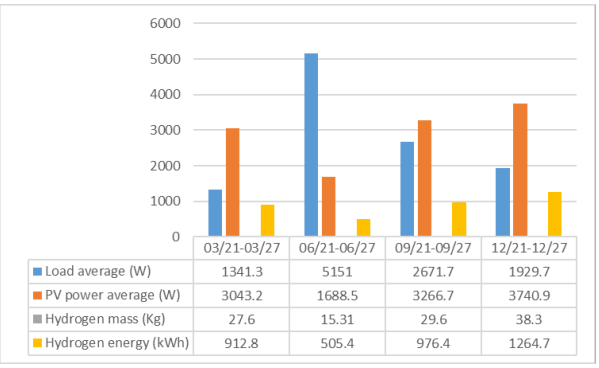
In the Matlab/Simulink model, major components (Figure 4), include the PV panels, PEM electrolyzer, and PEM fuel cell. The PV model incorporated ambient conditions (Ayaz et al. 2014, 1-6), while the PEM electrolyzer Simulink model was based on Albarghot et al.'s system model (2016). The PEM fuel cell Simulink model drew from Mathworks' system model (Mathworks 2023). To streamline the simulation process, it was assumed that all solar power generated by the PV system was exclusively dedicated to hydrogen production rather than directly supplying electricity to the building. Subsequently, all produced hydrogen was consumed for electricity generation. The simulation focused on the south façade of the building in order to assess potential impacts under different climatic conditions. Simulation duration spanned a week in each season: March 21st to March 27th, June 21st to June 27th, September 21st to September 27th and December 21st to December 27th. Expected outcomes included hydrogen production from the PV-electrolyzer process and electricity generation from the hydrogen-fuel cell process.

3.2. Results and Discussion

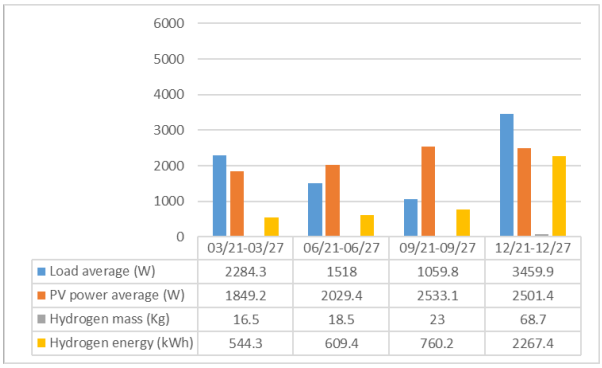
The simulated results suggest that summer is not the optimal time for harvesting hydrogen and that winter obtains the highest amount of hydrogen in both Phoenix and Chicago. This can be attributed to two main factors. Firstly, the installation of PV for solar energy harvesting on vertical façades leads to a larger zenith solar during winter, resulting in more irradiance hitting the vertical surfaces. Additionally, the temperature coefficient of power plays a significant role in influencing photovoltaic efficiency, with lower temperatures in winter leading to higher efficiency. Analysis of table 1 and figure 5 indicates that in Phoenix, summer requires more cooling load due to hot weather but the PV-RPEMFC system may not generate enough energy for residential building operation. In this scenario, all the electrical energy generated by the photovoltaic system will be directly utilized by the building. In Chicago, winter needs more heating load and does not result in hydrogen storage. However, when photovoltaics produce more power than building load under other circumstances, hydrogen can be produced for further use.

This research primarily aims to understand how climate variables, particularly solar radiation and temperature fluctuations, impact the hydrogen production output. It is crucial to acknowledge certain limitations inherent in the simulation results. The simulations were carried out using default settings in Matlab/Simulink for energy estimation, which may not precisely depict the performance of a specific commercial reversible fuel cell in real-world conditions. For enhanced accuracy, future simulations should model each component in the system based on manufacturer specifications. Our subsequent step involves constructing a Matlab/Simulink model that is more precise and aligns closely with the characteristics of the products described in the text. The metal hydride storage is tailored for a specific storage function, differing from the traditional approach of compressed hydrogen storage. However, even with meticulous modeling, disparities may persist due to factors such as internal resistance or other energy losses.

Table 1: A comparison between two locations: Phoenix (left) and Chicago (right). Source: (Author 2024)



	03/21-03/27	06/21-06/27	09/21-09/27	12/21-12/27
Load average (W)	1341.3	5151	2671.7	1929.7
PV power average (W)	3043.2	1688.5	3266.7	3740.9
Hydrogen mass (Kg)	27.6	15.31	29.6	38.3
Hydrogen energy (kWh)	912.8	505.4	976.4	1264.7



	03/21-03/27	06/21-06/27	09/21-09/27	12/21-12/27
Load average (W)	2284.3	1518	1059.8	3459.9
PV power average (W)	1849.2	2029.4	2533.1	2501.4
Hydrogen mass (Kg)	16.5	18.5	23	68.7
Hydrogen energy (kWh)	544.3	609.4	760.2	2267.4

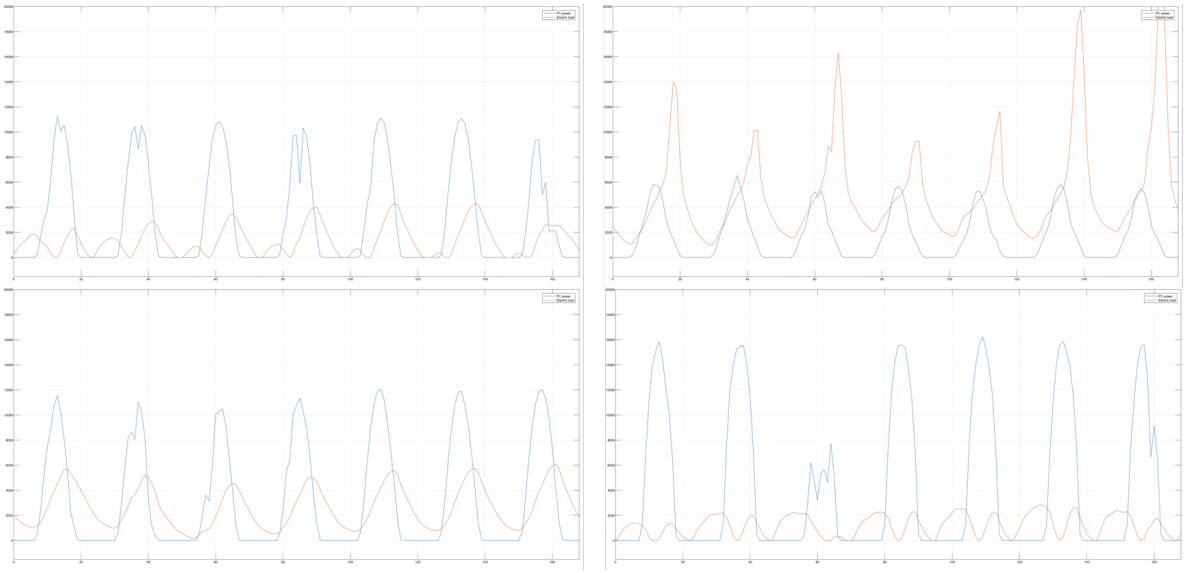


Figure 5: Phoenix: PV power (blue) and building load (orange). Top left: March, top right: June, bottom left: September, bottom right: December. Source: (Author 2024)

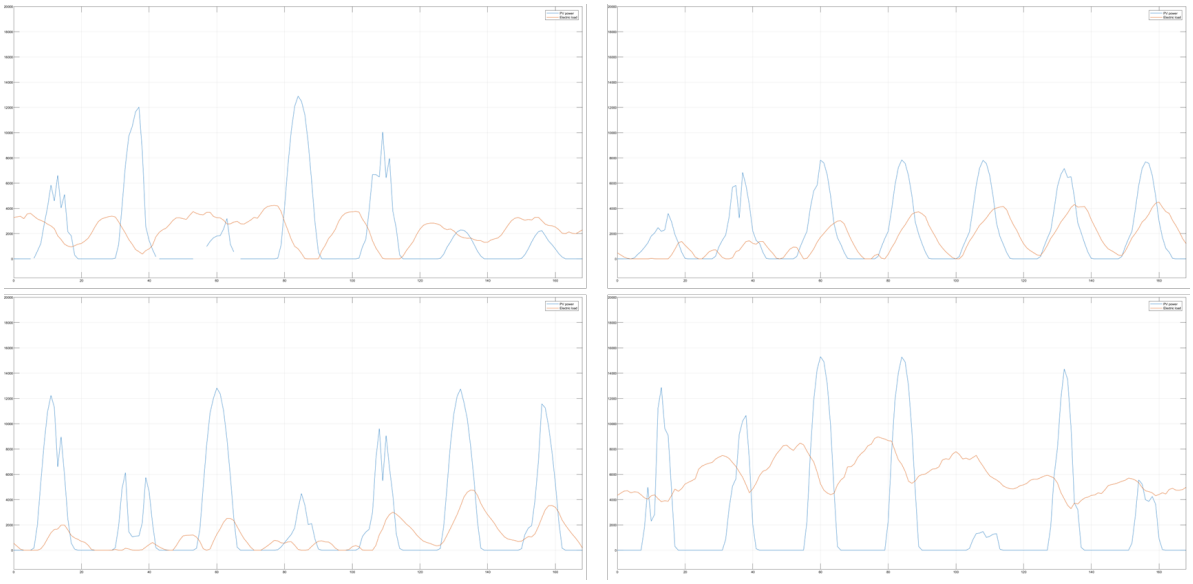


Figure 6: Chicago: PV power (blue) and building load (orange). Top left: March, top right: June, bottom left: September, bottom right: December. Source: (Author 2024)

CONCLUSION

To date, the research introduces a potential design for PV-RPEMFC cladding panels capable of harvesting solar energy, converting it into clean energy in form of hydrogen, and storing hydrogen. The stored hydrogen is then utilized to generate electricity, completing an energy storage process within buildings. In contrast to the conventional method of storing solar energy in batteries, RPEMFC offers scalability and does not involve the emission of greenhouse gases. However, given the current cost of reversible fuel cells, further electrochemical research is needed to develop more cost-effective and highly energy-efficient cells for widespread use in construction.

ACKNOWLEDGEMENTS

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Phygital Fabrication and the Evolution of Traditional Handicraft

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ABSTRACT: This paper untangles the emerging need for a critical understanding of phygital design and phygital material by exploring its most definitive qualities in the context of a quasi-autonomous collaboration between human agency and the computer, here explored through the digital reinterpretation of traditional handicrafts belonging to the ethnic Chinese minority Bai from the northwestern province of Yunnan. A phygital fabrication workflow challenges experience-based standardized fabrication techniques by creating atypical results from a constant exchange between physical fabrication and digital simulation, consciously acknowledging the contributions of the machine. It suggests, moreover, a new way to inherit indigenous design as a deliberate collaboration with non-human agencies, reflects the anxiety of designers seeking new positions around digital design tools, and describes a workflow not wholly defined but nonetheless integral to contemporary design practice.

KEYWORDS: Phygital, Materiality, Fabrication, Indigenous, Quasi-autonomy

INTRODUCTION

In her book, *Lo-TEK: Design by Radical Indigenism*, Julia Watson maintains that the mythology of technology, as a confluence of humanistic, colonialist, and racist tendencies, has historically disregarded local wisdom and indigenous innovation (Watson 2022). To resist the qualification of indigenous innovation as primitive and existing apart from "technology," designers must be conscious of the impact of modern tools on the cultural landscapes to which they are applied.

Ongoing advances in machine learning technologies continue to make artificial intelligence tools extremely accessible. The level of accuracy and sophistication generated by machines can now be easily confused with content created by humans. Established workflows from the artificial intelligence chatbot to text-to-image generators suggest that emerging digital tools are capable of autonomous design. The anxiety surrounding intelligent digital tools is palpable in the design industry today. Indeed, what is the value of human agency to a creative process informed by artificially intelligent machines whose processing power and memory are a billion times more advanced? Renowned American literary critic Harold Bloom once stated that artists must be aware of this anxiety of influence but must also strive to create something new and unique that advances and transforms it (Bloom 1997). We concur, maintaining that the new human-machine relationship must be critically examined.

Digital design tools have been used in various industries for several decades, prompting the constant re-evaluation of the human-machine relationship. The introduction of Computer-Aided Design (CAD) tools in the 1960s and 1970s marked the beginning of the digital design revolution. CAD tools allowed designers to create and modify designs using computer software, increasing productivity and accuracy. The computer was considered a powerful tool, a buffed-up drafting table (without autonomy) that could create optimized and efficient drawings. The machine output being a direct response to human input meant that it could be easily evaluated by its user. In the early 21st century, the advent of cloud-based software and collaborative design tools with BIM (Building Information Modelling) technology enabled designers to work remotely. BIM models rely on accurate input data and designers' skilled interpretation, which require additional expertise and training to avoid errors or oversights. Now, working with AI, the bar should be even higher for designers to interact with the machine consciously. However, designers are not trained as computer science engineers. For most, the computer is a black box, a mechanism of mystery, when engaging with automated tools. Consequently, it can produce many unintentional outputs that are exceptionally difficult, if not impossible, to evaluate and control.

How can designers be more conscious about working with the engaged tool? Creating a quasi-autonomous workflow could be an answer to this question. In his article, "Quasi Autonomy in Architecture," Stanford Anderson maintains that a collaborative approach to the design process is required to avoid complete autonomy. There is no imperative that we must use any given technique (Anderson 2002). Friction between humans and machines is needed to create such a collaboration. When human agencies apply experience-based knowledge to a workflow, machines can output with optimized, automated, and limitless possibilities waiting to be curated. Phygital design incubates this collaboration by engaging both the physical understanding of material, fabrication, and construction from human agencies and the digital non-rectilinear translation from machines (Figure 1).

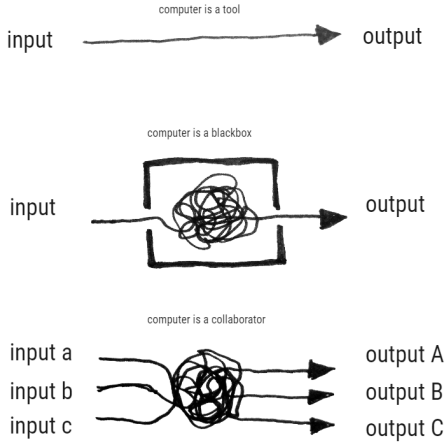


Figure 1: Diagram of three types of human-machine relationships. Source: (Nero Chenxuan He 2022)

1.0 METHODS

An example of phygital material fabrication, created in collaboration with a Chinese artist, is introduced here to evaluate the phygital design process. The artist samples traditional handcrafted tie-dye artwork from the Bai nationality of China. Bai tie-dye is a coloring technique representing various symbols, patterns, and meanings. The representation of the tie-dye requires a complex process handed down from one generation to another by word of mouth. Locals stitch fabrics in different manners, which allows fabrics to have different contact areas when dyed in a large container. After the fabric is dyed and dried, the stitches are removed to reveal the stained patterns. It requires 17 unique steps to finish a traditional Bai tie-dye work (Figure 2).



Figure 2: Indigenous Bai tie-dye process. Source: (Unknown 2019, Shuying 2017, Zhiqiang Liang 2021)

The phygital fabrication process begins by inheriting the stitched sculpture-like fabrication techniques of the local community; it samples identifiable patterns of the material artifacts and simulates their behavior in a digitally enhanced but physically consistent way. In so doing, the phygital workflow not only translates but transforms traditional knowledge through the vision of a machine (Figure 3). Translating from physical fabrication to digital simulation (and vice versa), phygital material fabrication provides an ongoing process to present atypical fabrication possibilities.

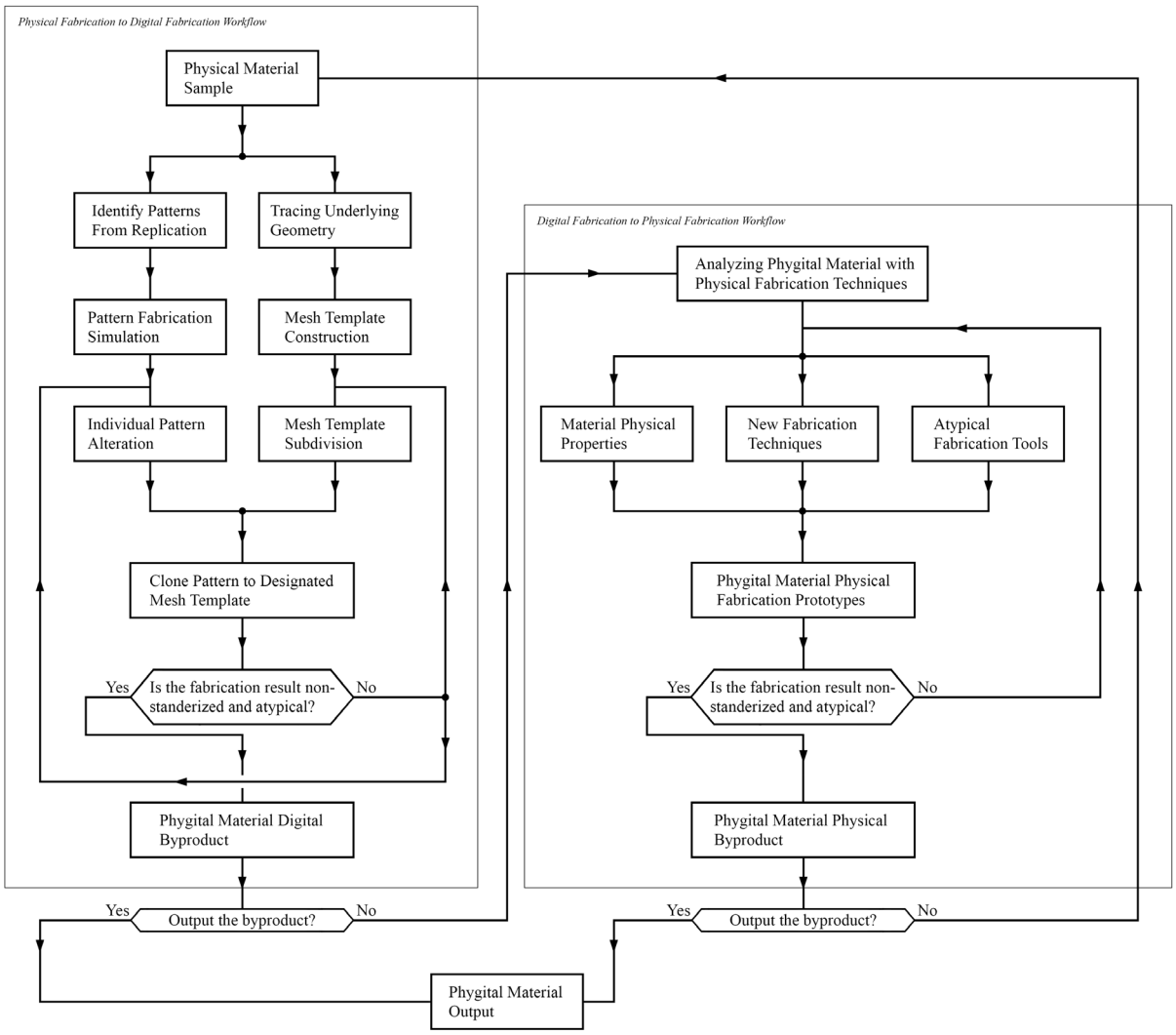


Figure 3: Phygital fabrication workflow chart. Source: (Nero Chenxuan He 2023)

1.1 Physical-to-digital fabrication workflow

To simulate the fabrication digitally in an efficient and automated manner, the translation from physical to digital must engage the proficiency of a computer for outputting consistent results. A new application logic, a template, should be designed for the computer to follow, attaching each replication to form a structural result consistent with the physicality of the artifact.

Identifying the replication in patterns is the first step to sampling from the physical fabrication. *In The Art of Manipulating Fabric*, Colette Wolff categorizes various fabric manipulation techniques, including pleating, gathering, smocking, quilting, and applique (Wolff 2003). These techniques can be rationalized by a computer with simulation forces mix-and-matched (Figure 4). The simulation is “fluid, responsive, and time-based,” as Greg Lynn observes in *Animate Form* (Lynn 1997). It creates a range of results sharing the same logic but formally altered from one another.

The difference in fabric patterns leads to a curation operation for the designer to evaluate and then selectively attach patterns to templates in order to diffuse the cloning and tiling nature of the process (Figure 5). This procedure artfully engages with the UV structure of a mesh surface and computational coning operation to maximize the power of the computer as a design agency. The simulation also implies a direction for material behavior in the fabrication, which will be discussed in the digital-to-physical fabrication workflow.

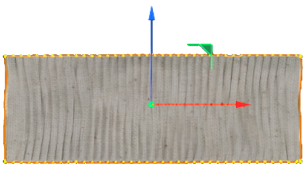


Figure 4: Single pattern fabrication simulation. Source: (Nero Chenxuan He 2023)

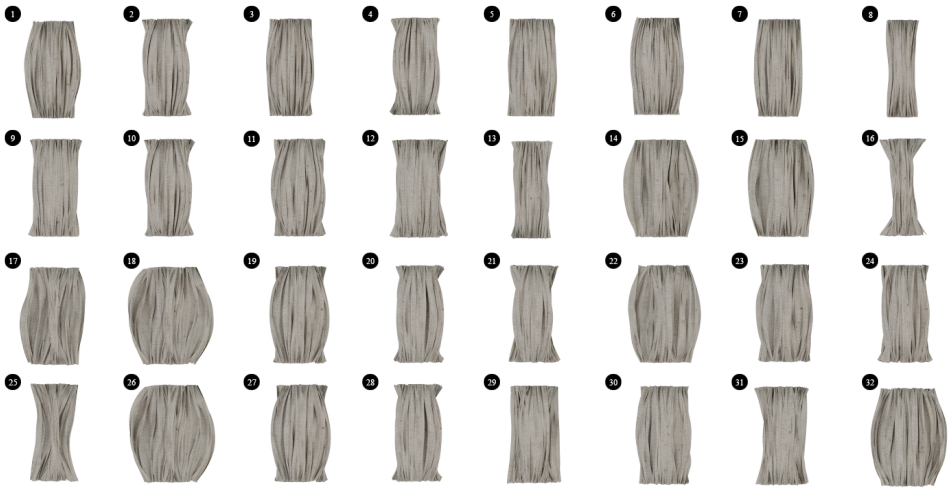


Figure 5: Curated results of single animated simulation. Source: (Nero Chenxuan He 2023)

The workflow is created to necessitate interference from human design agencies. Besides curating simulated patterns, the designer engages with the construction of fabrics by adjusting the scale, orientation, density, or materiality of the sampled pattern and the correlated template (Figure 6). If the result is excessively standardized, more alterations are needed.

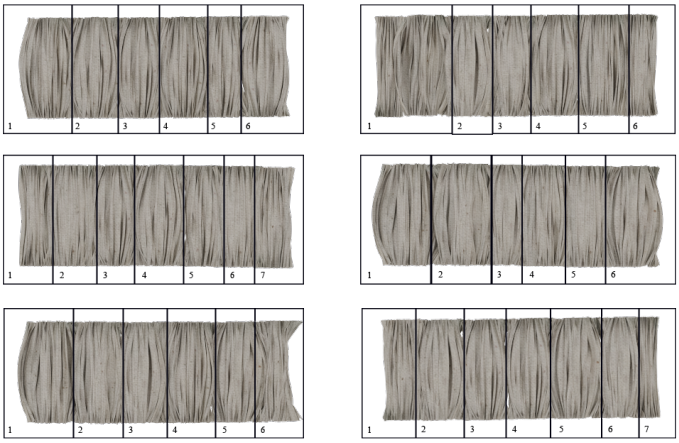


Figure 6: Pattern curation on templates. Source: (Nero Chenxuan He 2023)

Due to the abundance and complexity of the simulation, the simulated fabric is difficult to make visible in the design interface without crashing the computer. The process is bounded by the limitation of operated software and machinic hardware. Only by rendering out temporary results in real-time can the digitally fabricated product be critically evaluated (Figure 7). In this way, the limitation of conventional computer hardware necessitates another layer of digital perspective.



Figure 7: Phygital fabrication interface and real-time render result. Source: (Nero Chenxuan He 2023)

1.2. Digital-to-physical fabrication workflow

In this step, a collaborative process employs experience-based knowledge to identify atypical artifacts from the digital simulation (Figure 8). Each artifact challenges the designer's understanding of the behavior of physical materials and the capabilities of traditional fabrication techniques and tools.

In the digital domain, rendered material can be detached from its material behavior. When a digital material does not follow physical rules, it calls into question the nature of established fabrication techniques and tools (used for mass production and standardization) and generates an impetus for innovation and customization. The physical fabrication of this digital artifact should not, then, aim to recreate it as a physical clone. It should, instead, embrace the technological limitations of fabrication and make further alterations (to the digital) with consideration (of the physical) (Figure 9).



Figure 8: Physical pattern fabrication studies. Source: (Fanglu Lin 2023)



Figure 9: Phygital fabrication: digital byproduct (left) and physical byproduct (right). Source: (Nero Chenxuan He and Fanglu Lin 2023)

2.0 RESULTS

Phygital design is the last line of defense claimed by designers who fear losing agency in an industry that continues to contend with advances in automation. Design is a cultural practice. An intelligent machine, without guidance, can only sort and recombine information. The machine needs inferior human agencies to mediate its relationship with a physical world that (for now) it has a limited understanding of. When introducing the replica of Gordon Pask's 1968 "Colloquy of Mobiles," Paul Pangaro questioned the future of the machine by asking whether it should:

> predetermine everything for us, make the calculation in advance, and be the smartest AI in the cloud that tells us what we want to see every moment in the world? Or it should create "something playful, sometimes random and unexpected, something special? (Pangaro 2018).

While digital creation uses logic to simulate an optimized / automated / limitless possibility, human agencies assess, curate, and fabricate work by assigning physical concepts. Without interference or interpretation, the digital result is nothing but representations from calculated numbers. Just as the design of the pencil was informed by the dialogue between technological capability and human intention, the tools of phygital design must be continuously re-examined through the lens of contemporary contexts and conditions.

2.1. Not all digital is phygital

Phygital is conflicted. It seeks exchange but not synthesis. To understand how phygital design works, designers must accept that not all digital is phygital.

A phygital design establishes a two-way exchange from physical to digital and the other way around. In the simulation, there is no physics until a person with a physical understanding projects physics onto the representation of the performance of objects calculated with mathematical concepts. Material behaviors and material appearances can be mismatched but must ultimately be post-rationalized with knowledge of fabrication and construction.

2.2. Phygital has no finite result

Phygital is an endless physical and digital seesaw. There is no finite result, only byproducts and fractures of this push and pull. A phygital object carries a fabrication logic of how a physical piece comes to be. Thus, its result could always be reanalyzed by an optimized digital representation which drives a new type of physical fabrication. Residues from both physical and digital processes are welcomed to create friction and challenge established knowledge.

2.3. The friction from translation

Phygital exists as friction between the physical and digital. The goal of each translation is not to create an identical double from another medium. Instead, a logical reconfiguration is needed with the accessible procedure in the medium to which the product is translated. The information exchange will inevitably produce friction, which is preferred over the homogenized representation attempted by projects like the Cornell Box.

In the elaborate para-fiction, *Understanding Molecular Typography*, by H.F. Henderson, artist protagonist Woody Leslie forces the logic of shaping and structuring molecules onto the visual representation of typography (Leslie 2019). He presents the result as an artifact that is as critical to document as the recognized waypoints of "correct" schools of thought. By introducing an alternative logic to existing information, this sophistry explores the possibilities of creating atypical results from translational friction (Figure 10). When an input is effectively finite, therefore – e.g. bounded/defined by the parameters of traditional knowledge, the computer as an intermediary performs the historical operation of cultivating variations by outputting mistranslations.

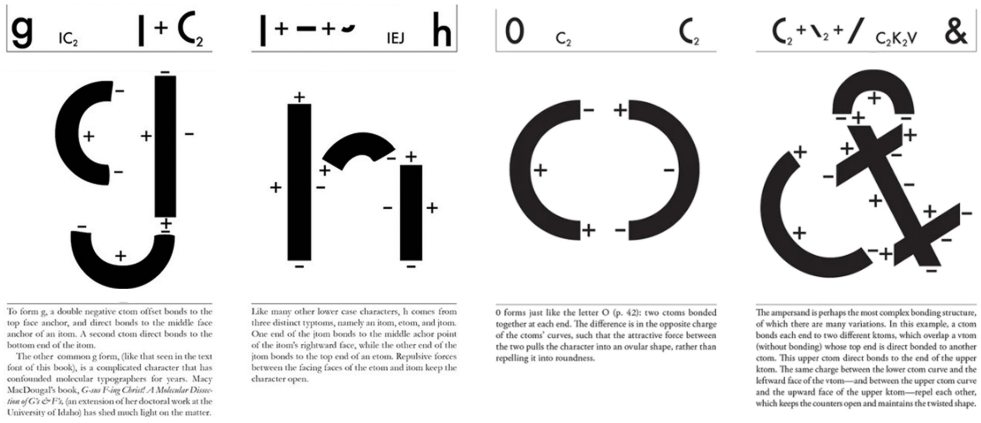


Figure 10: Understanding Molecular Typography. Source: (Woody Leslie 2019).

3.0 APPLICATIONS

Phygital fabrication techniques can be applied to any fabrication process that contains a traditional, linear design workflow (architecture included). Each sequence of fabrication events can be challenged by engaging with the computer simulation (the imitation of the operation of a real-world process or system over time), combined with the designer's curation (the process of receiving or giving systematic instructions).

Resistance to standardization is not a new phenomenon. The Arts and Crafts movement of the late 19 and early 20 centuries emerged in response to the perceived detriments of standardization linked to industrial machines and factory production. William Morris, one of the figureheads of this movement, designed the Red House to emphasize the designer's curation – the totality of craftsmanship – by exposing and exaggerating hand-crafted interior elements. This approach denied the benefits of engaging with non-human agencies.

The application of phygital fabrication celebrates craft *over* craftsmanship. The end goal is not the digital appropriation of human crafting techniques; it is, rather, the creation of an atypical craft that acknowledges and engages both agencies. In an alternative example of non-phygital design, the creative aggregation undertaken by Dennis Maher presents the results of accumulated labor over time in the absence of craftsmanship / design curation. The labor of phygital fabrication, however, is still meant to involve curation, so that the outcome evidences a deliberate awareness of the tools and techniques which have been applied to the work.

Despite also demonstrating digital residue (like the phygital fabrication process), parametric design is substantially a form-making workflow dissociated from material fabrication. By shifting forms, orientations, and/or colors, the physical index of material curation which is inherent to phygital design inherits traces of its digital counterpart, which may manifest as the result of an executable/economical fabrication solution. Parametric design, however, has not generally given priority to challenging design through crafting; rather, it has celebrated the formal (micro and macro) results of scripting language.

Phygital fabrication is a design-oriented methodology engaged as a deliberate curation of computer simulation. It is an exchange between physical fabrication techniques and digital simulation workflows. It unabashedly extols the collaboration of the human designer and the machine. Designers need to apply experience-based knowledge to the simulation process and then directly manipulate relevant variables. Computer simulation, when compared to 3D modelling tools, allows for an alternative approach to fabrication, particularly through the metric of time. The notion of time within simulation software is an abstraction; it is an elastic number which can be slid, stretched, paused, and reversed. Digitally simulated time is neither true time nor absolute time; it is a physical input (like gravity, illumination, and materiality) which is dependent on the understanding and curation of human designers. Without deliberate human engagement, the outcome of simulation (the nature of its relationship to time and space) presents as a meaningless visualization of calculated binary numbers.

Within the back and forth of translations from the physical to the digital, due to the limitations of software and hardware, the simulated design is inevitably 'optimized' to a legible digital standard, which is different from the absolute standard for material fabrications or constructions. Through the process of documenting, dismantling, simulating, restructuring, and making, phygital fabrication enables the atypical exploration of architectural tectonics, proposing new possibilities for formulaic materials, tools, and means of evaluation.

CONCLUSION

Phygital fabrication is an exchange between physical fabrication techniques and digital simulations. Due to the limitation of software and hardware, the simulated design is inevitably 'optimized' to digital standards, leading to an atypical outcome (when compared to a standardized physical precedent). After curating different sets of outcomes,

the digitally fabricated piece becomes physical through an idiosyncratic exchange with fabricators or fabrication machines. Thus, phygital fabrication compels an endless physical and digital translational seesaw averse to synthesis. There are no procedural results from this push and pull, only byproducts. The physical project has a digital residue, and the digital project has a physical residue.

Phygital fabrication, in its digital presence, is not an image slapped on a digital surface; it has volume, weight, and material behavior. Since the energy required to produce material is a substantial factor in the raw material cost, the value of the phygital material has its own economy. The digital waste from the process is negligible. In its physical presence, phygital fabrication, while inheriting the tradition of the indigenous artifact, challenges the standards of fabrication techniques and used tools.

Phygital fabrication, physically manifested, carries deliberate traces of the digital workflow. The storefront presents the output of the aforementioned material exploration as a speculative consequence of digital optimization and limited hardware capacity, calling into question how the phygital workflow may influence the development of building materials and fabrication technologies as a speculative expression of the ever-changing interrelationship between people and machines (Figure 11).



Figure 11: Phygital fabrication exhibited at a storefront. Source: (Nero Chenxuan He and Fanglu Lin 2023)

Phygital design introduces new design possibilities through the exchange of digital and physical design mediums. The consistent and mutual interference by human and machine agencies is an established (albeit primarily unconscious) dynamic. Phygital design is neither the exclusive application of human intelligence nor total digital autonomy; it is the creative exchange of both agencies culminating in a deliberately unsynthesized design. It represents the spirit of an age before the synthesis of the virtual and the real, before VR glasses become VR eyeballs, before cyborgs or biomechatronics, or the augmented person.

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Circular Immersive Parametric Design Workflow for Innovative Materials

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ABSTRACT: There is sufficient evidence that the use of Building Information Modeling (BIM) and Virtual Reality (VR) in Architecture, Engineering and Construction (AEC) education environments is desirable and beneficial. This study introduces a workflow for circular immersive parametric design (CIPaDe). The proposed CIPaDe, BIM-into-VR-based workflow is expected to improve students' learning performance, provide an environment similar to real-world, increase the visualization of models on a larger scale, and enhance their creativity. The CIPaDe Workflow includes stages of 1) material selection for non-loadbearing elements 2) geometry exploration and VR sessions 3) life cycle assessments (LCA). Secondary materials for LCA were selected from declared products on the Embodied Carbon Construction Calculator (EC3) Tool. The goal was to arrive at a design with minimal embodied carbon and energy. The intersections of material choices for innovation and sustainability provides the opportunity to test its impact through embodied energy investigations and operational energy impacts. Emerging designs are the basis for comparisons between recycling and virgin materials. The results show that the novel workflow utilizes BIM and VR to promote circularity and provide environmental benefits.

KEYWORDS: Circular Design, Materials, Building Information Modeling, Sustainability, Virtual Reality

INTRODUCTION

A major challenge of the AEC industry is the inefficient approval process due to the slow adoption of modern technologies such as Building Information Modelling (BIM), Virtual Reality (VR), Augmented Reality (AR), and cloud computing (Hartmann et al., 2009; Khan et al., 2021; Mehrbod et al. 2019). The design process for AEC is iterative and relies strongly on individual experience (Ahmed 2018), and there is a developing ecosystem of content for millions of available VR headsets and devices. Much of this content include games or game-like social experiences and many other diverse activities. As this VR mediums become more popular and mainstream, there is need for the Architecture, Engineering and Construction (AEC) industry to adapt to the growing awareness of the technology. The recent exciting commercial developments refreshes interest in the promise of these technologies to support the iterative design process. Three-dimensional (3D) design programs allow designers to explore their ideas in the digital (Aprilliandini 2020). The use of VR in the AEC design process was explored using a BIM program. A design activity that incorporates VR gives users the ability to move from a two-dimensional (2D) spectator experience to an actor in the 3D environment that is the object of study. VR designing offers many advantages, it is easy for the users to handle, they quickly form ideas at scale, they collaborate in real-time and they communicate their ideas (Drampalou 2022). It is essential that VR use is embraced by the AEC to enhance the design process, discover new ways of expression, and develop new ways of adopting available technologies.

Despite the potential advantages of adopting modern technologies, there are considerable challenges to implementing VR applications. The use of gaming engines such as Unity 3D and Unreal which are frequently utilized for VR development require a significant level of expertise limiting the adoption of VR systems in the field (Globa et al. 2023). This study suggests leveraging the commercially available Enscape software application and the MetaQuest VR headset to construct an alternative approach for VR adoption in the design process for the AEC industry that takes less time.

Previous studies have demonstrated that the adoption of VR supports the design review process by identifying design errors and improving communication, collaboration, and decision-making. It provides an interactive, engaging, immersive, and realistic presentation of space (Liu et al. 2020). For instance, students conducting design reviews in a classroom environment using VR determined a higher number of design mistakes and performed significantly better than those using 2D drawings, (Kandi et al. 2020).

The concept of circularity promotes the use of materials for as long as possible in closed loop systems. CE means that products no longer have a life cycle with a beginning, middle, and end, therefore this can reduce waste and add value to their ecosystem (Ellen Macarthur Foundation, 2024). The CE is based on three principles, driven by design: 1) eliminate waste and pollution, 2) circulate products and materials (at their highest value), 3) regenerate nature. CE is constructed on the 9R framework: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover (Kirchherr et al., 2017). The CE tackles climate change and other global challenges like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources (Ellen Macarthur Foundation, 2023).

The world is becoming less circular, moving from 8.6% in 2019 to 7.2% in 2023 as reported by the circularity gap report. (de Wit et al, 2018; Fraser et al. 2023). It is imperative that designers explore digital strategies to increase circularity. VR can be used to simulate the building process and identify potential issues that could help construction companies avoid costly mistakes and reduce material waste (Soman et al. 2024). (Lee & Leite 2023) sought to promote circularity by an immersive experience integrating physical and digital worlds that allowed users to interact with digital objects which were overlaid with the actual world resulting in a more effective learning experience. VR has become prevalent in our daily lives and have been integrated into meeting the principles of circular economy (Bucea-Manea-Ţoniş 2021). VR could be used as a tool towards engaging individuals in sustainability especially circular economy, a prototype showing the transition from a linear to a circular economy led to an affirmation from testers of feeling more engaged and motivated to live more sustainably (Aune & Ghattas 2023).

This manuscript reports a design activity of building design students paired in teams and designing an education building. Two VR sessions were part of the design process and students discussed their experience during the immersive process. Teams submitted their reports including their perception of the VR sessions. Findings showed that students could actively engage with their content by providing feedback in situ.

1.0 RESEARCH METHOD, EXPERIMENTAL SET-UP, AND PROCEDURE

1.1 Research methods

This research study adopted a mixed research method and implemented a case study to investigate the potential of VR activity for design iteration exercises in building design education using an educational office building design as an example. The cohort was made up of 20 students in ten teams. The design activity commenced with material selection, design of units, two design reviews with VR sessions and a final report. Responses to the VR sessions in the report were analyzed to determine the effectiveness of the new immersive approach, Figure 1. This study follows LCA stages described in ISO 14040 (ISO 14040 2006).

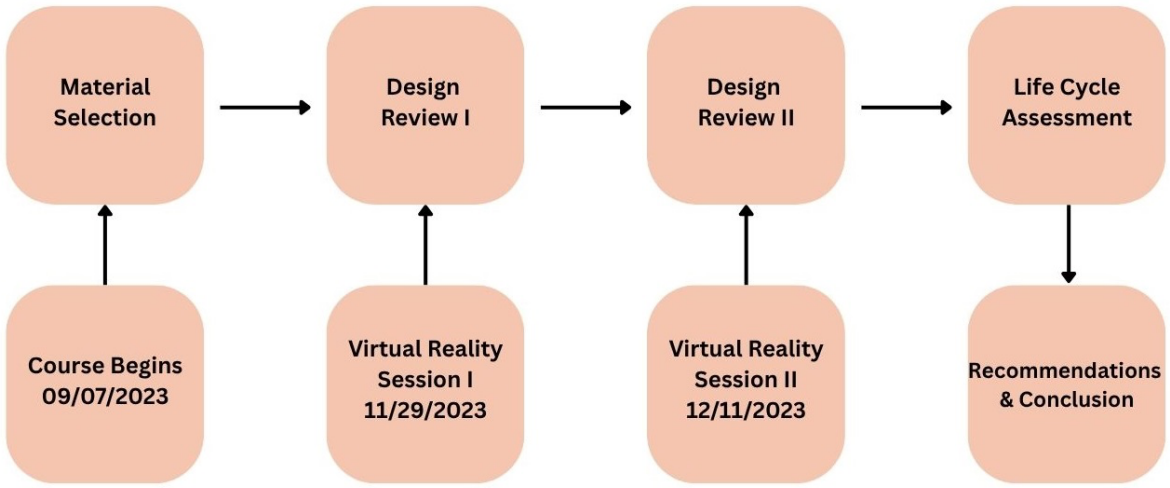


Figure 1: Research method for VR sessions. Source: (Author 2024)

1.2. Course pre-survey

The students were given an 8-question pre-survey comprising questions focused on their understanding of sustainability and experience with VR headsets. 85% of the students responded, their responses to the question – “What does sustainability mean to you?” comprises - routine, able to function for an extended period of time without having a large negative impact, the ability to maintain something that will last forever, sustainability is being able to maintain at a certain level, sustainability are energy efficient practices and materials that last, having little to no carbon output, Green Building / Green Energy that doesn't compromise the environment, the ability to be maintained at a certain rate or level, the reuse of energy efficiently whilst limiting and reducing waste, sustainability means meeting the needs of today without compromising the ability of future generations to meet their own needs, to be able keep up with the work that you have and do it well, a way to describe the longevity of a system to continue performing the desired action, making a conscious choice to use the minimal effective resources, and reduce waste as much as possible, sustainability would be the use of materials or practices that won’t hurt the future generations, able to keep track in a consistent manner, fulfilling the needs of current generations without compromising the needs of future generation, sustainability to me means living a way of life that allows one to keep doing so without negatively affecting things or people around them or impacting the resources around them. 53% of the students had use a VR headset before the course and 100% of them used the headsets for games, 91% used them less than once a week and 9% had used them only once. 35% of the students were familiar with the term parametric; 33% were familiar with Revit Software, 30% were familiar with AutoCAD, 11% were not familiar with any BIM software, 7% were familiar with Sketchup and other software mentioned include Tinkercad, Chief Architect, Keycreator and Envisioneer.

1.3. Design case study of an educational building

In one semester for a building design course, students were asked to design an educational building and the sustainability inquiry was limited to a south facing shaded wall. Student teams were required to design a parametric patterned wall for the purpose of substituting traditional materials with reused sustainable materials. The goal was to divert as much waste from landfills as possible. The designs of three teams (six students) are presented in this study. The teams designed shaded walls applying different forms of geometry. The design process was divided into two parts- building as a whole and the shaded wall. Students designed units for their wall before proceeding to produce them in Revit BIM software, Figure 2.

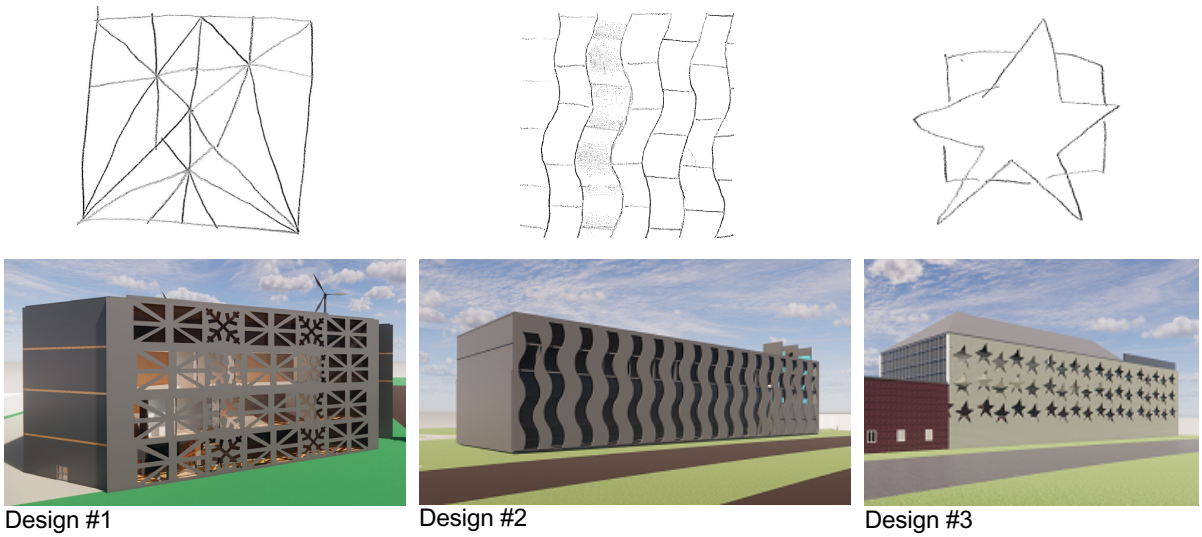


Figure 2: Design of South-facing shaded wall by teams showing sketches and walls. Source: (Author 2024)

1.4. Material selection

Teams were asked to select materials from the Embodied Carbon in Construction Calculator (EC3) tool for their shaded walls. The data given for the materials would be used for a life cycle assessment (LCA). Design #2 team selected NOREX Panels from EC3 for the shading material. This was used as the alternate throughout.

1.5. Virtual reality sessions

There were two VR sessions during the design process. The goal was for students to experience their design and report its impact on them as users. The equipment used were a personal computer (PC) Lenovo gaming laptop, air link cable from Facebook, and a Meta Quest 2 VR headset. The headsets required Oculus software and further steps included downloading of airlink software, begin VR, plug usbc cable. On laptop, settings, system> quest link > access PC/VR > launch quest link > launch rift. Students produced their project in Revit. The instructor explored Unity, Twinmotion and Enscape softwares and Enscape was the easiest to use, however students did not have laptops that met the requirements to run Enscape. Therefore, the instructor's gaming laptop was used for the VR sessions, Figure 3.

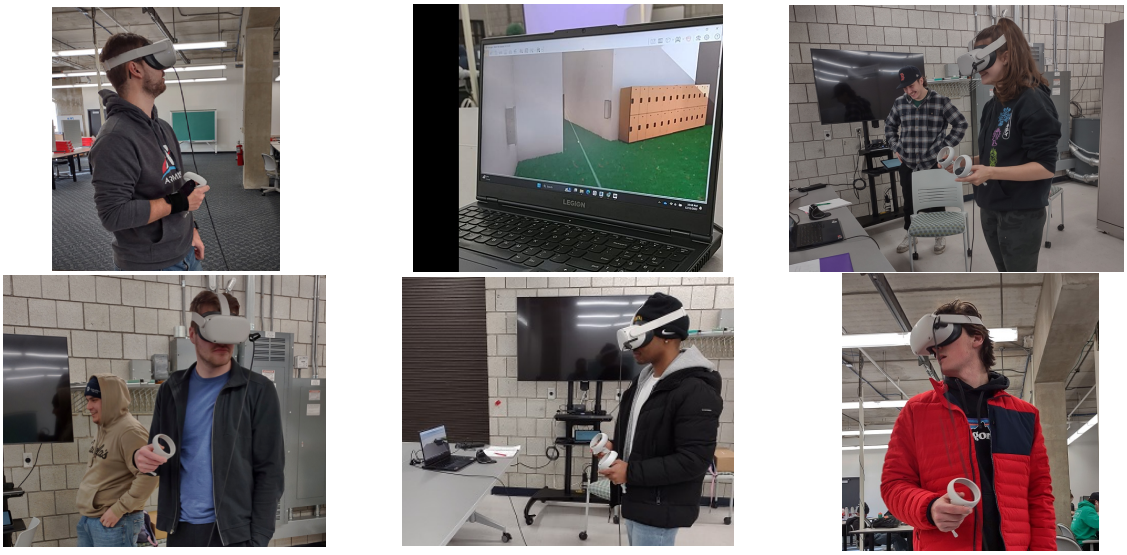


Figure 3: Students during virtual reality sessions. Source: (Author 2024)

2.0 RESULTS

2.1. VR design observations

Students assessed the projects as users and spent an average time of 5 minutes for 18 sessions in the VR environment. The range of time spent was 2 – 10 minutes. Students voluntarily critiqued their design when immersed in the building environment. The most mentioned areas for improvement were the walls (8), windows (7), staircases (6), and building pads (6). Other areas included furniture, ceilings, and handrails Table 1. Thirteen out of twenty students participated in the VR session and nine out of ten teams were represented in the VR sessions, one student declined to participate sessions.

Table 1: VR sessions and action points observed. Source: (Author 2024)

Session 1 Time (minutes)	Student observations	Session 2 Time (minutes)	Student observations
			Set height of crane; building pad; notices furniture placed; exclaims
5	Add floor; adjust furniture arrangement; floating objects	5	that VR exercise is cool!
4	staircase on the roof; adjust window; create building pad		
2	Improve furniture arrangement in a laboratory		
7	Adjust ceiling at stairs; Provide additional windows; seats were cramped; create circulation space; impressed with the geometry of the parametric wall: noticed curves and height of spaces		
	Adjust roof; floating walls; building pad; open slab above stairs; noticed crowded light		Add walkway to roof garden; add doors; elevator and stairs;
5	fixtures; stated that there was much work to be done	10	at library open floor above the stairs; correct wall heights;
5	Add windows; doors; furniture; floor; handrails; change location of doors	3	Add building pad; add ceiling; move spiral stairs away from wall
5	Remove slab over stairs; add windows		
3	Adjust wall heights	4	make window bigger; adjust window height; building pad
2	change form; increase corridor; adjust wall heights; Increase sizes of classrooms		
	staircase is assuring; generated design idea for hallway space; add doors and windows; drop ceilings in bathroom; appreciates seeing building in 3D; suggests future use and project it could be used in; says it would be useful for deaf and accessible		Observed atrium; narrow hallway; add slabs;
8	housing tenants	7	considered shape of bathroom
		7	Would change the direction of solar panels; cover stairs; add lockers; add handrails
		5	remove windows at roof level; likes white walls; add building pad
		5	noticed lines on walls, concerned about details and fire rating

2.2. Perception of VR sessions

In their report at the end of the semester, team members responded to questions on a user experience survey, six students responded to inquiry on the VR sessions. Students strongly agreed that the VR sessions were innovative, new, interesting, exciting, attractive, practical, efficient, dependable, motivating, and enjoyable, Figure 4. They agreed that it was organized, clear, pleasant, good, valuable, easy to learn, creative, and understandable. A few students strongly disagreed that the sessions were friendly, dependable, easy and easy to learn.

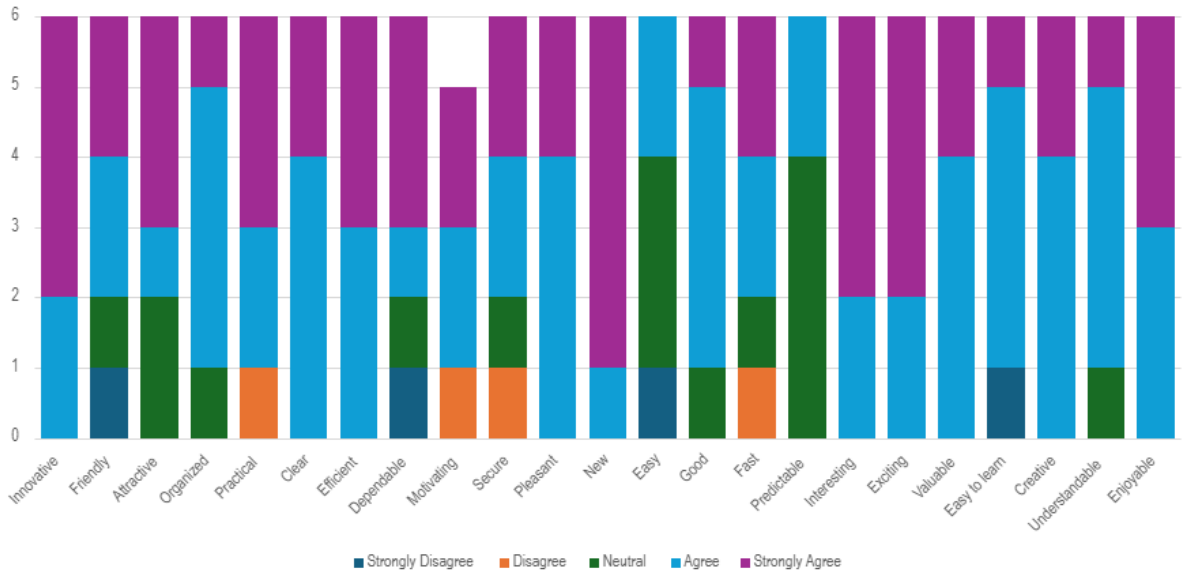


Figure 4: Students' responses to a user experience survey. Source: (Author 2024)

3.0 LIFE CYCLE ASSESSMENT

3.1. Process

The LCA was conducted following steps defined by the International Standards Organization (ISO) standards for measuring environmental impact (ISO 14040 2006). The LCA includes the following steps: goal and scope definition, inventory analysis, impact assessment, and interpretation Figure 5. The goal was to evaluate the environmental impacts of using the selected material from EC3 tool and the alternate scenario of using recycled material from the city through a cradle to gate approach. The assumptions for the study were that transportation distances were similar for both scenarios.

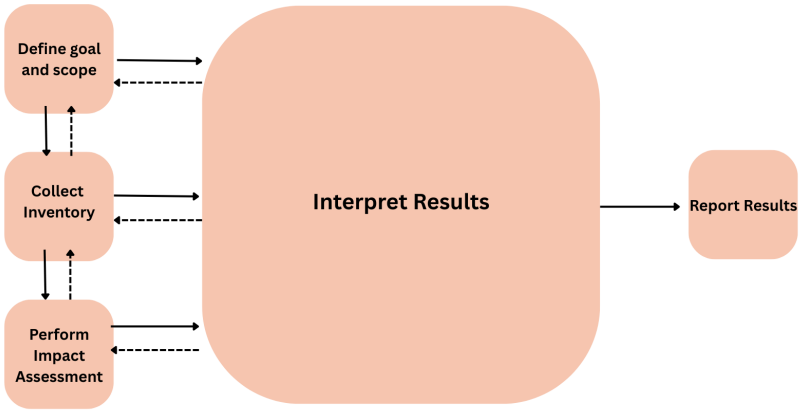


Figure 5: Diagram of the LCA process. Source: (Author 2024)

This study utilizes the United States Environmental Protection Agency's Waste Reduction Model (WARM) as the main data source for calculating greenhouse gas emissions and avoided energy. Additional data was obtained from the City of Fitchburg waste data from 2010 to 2020. The annual average availability of scrap metal was 74,933.5 kg (82.6 tons), Figure 6.

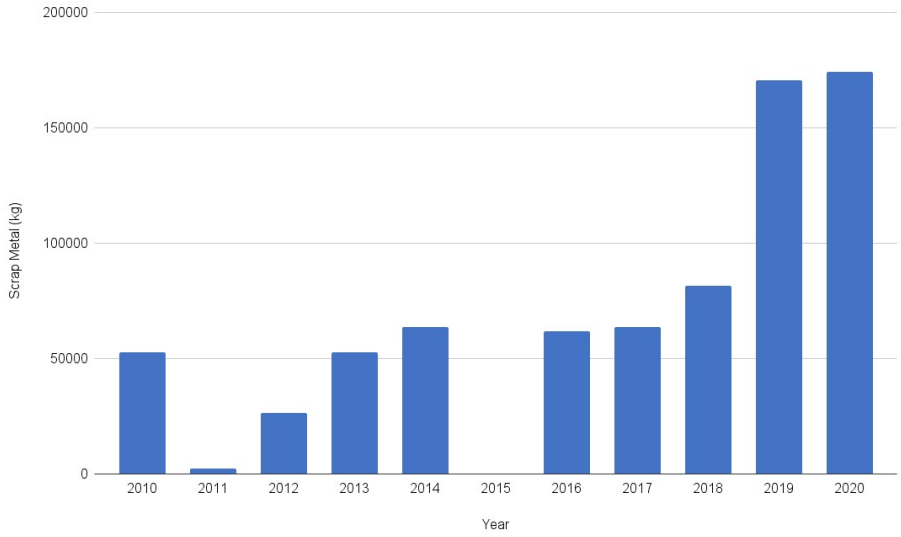


Figure 6: Scrap metal data from the city of Fitchburg, 2010 to 2020. Source: (Author 2024)

3.2. Functional unit modules

Three designs of exterior shades were used to compare the annual quantity of metal reused from. Student unit designs were in modules of 800 x 800 mm (331.5 x 31.5 inches), Figure 7. This was the functional unit to compare it with alternative traditional materials found on the EC3 tool for the same product. The total area of shaded walls from the designs were 1,118.18 m2, 2,300.28 m2, and 2,071.63 m2 respectively.



Figure 7: Waste data in tons 2010 to 2020 (scrap metal (blue), newspaper (orange), cardboard (grey). Source: (Author 2024)

The alternate traditional material from EC3 tool was NOREX Panels with a declared unit of 100m^2 and the mass per 100m^2 was given as 2500kg. The adjusted global warming potential (GWP) per 100m^2 was given as 4550 kgCO2e (EC3, 2023). The thermal resistance was given as 4.46 (km^2)/W, thickness 88mm, insulating material was polyisocyanurate and the facing material is steel. The panels are insulated metal panels with a polyisocyanurate (PIR) core designed for highly efficient buildings. The study assumed similar mass and thickness from NOREX Panels for the designs. The total surface areas for Design #1, #2, and #3 were 1,118.18m2, 2,300.28m2, and 2,072.63 m2 respectively. Applying the 100 m2 declared unit to the designs, using the NOREX panels for the design would result in GWP of 50,877 kgCO2e; 104,663 kgCO2e; and 94,259 kgCO2e respectively. The mass was the basis of a second analysis carried out in WARM to validate the avoided energy. If 100 m2 weighs 1240 kg then the total weight of panels per design was 13,865 kg; 28,523 kg; and 25,688 kg.
In WARM tool, the baseline scenario of recycling for steel cans was selected. The weights of the panels were converted from kilograms to tons and input in WARM to obtain the GWP when recycled materials are the secondary materials, the GWP were 25,410 kgCO2e; 52,250 kgCO2e; and 47,070 kgCO2e respectively, Table 2.

Table 2: Environmental impacts of using recycled material. Source: (Author 2024)

Design	Area(m^2)	EC3 GWP (kgCO2e)	Mass (kg)	Mass (tons)	WARM-GWP (kgCO2e)
1	1,118.18	50,877.27	13,865.45	13.87	25,410
2	2,300.28	104,662.53	28,523.42	28.52	52,250
3	2,071.63	94,258.95	25,688.15	25.69	47,070

4.0 DISCUSSION

4.1. VR session

In the presented study, VR sessions were introduced into a sustainable design project and the students strongly agreed that it was new, innovative, interesting, exciting and enjoyable. In addition, students self-critiqued their

designs and suggested ways to improve the spaces in their designs. They suggested solutions for walls, ceilings, windows, doors, staircases, railings, floors, and furniture. This study demonstrates how VR sessions can elicit interest from individuals in a design activity and communicate understanding of forms through immersion. The results of this study demonstrate that within a time range of 2 – 10 minutes spent per individual during a session, students could gain insights into the nature of their design. Responses from the reports showed that the students thought that the VR sessions could be easier.

4.2. Impacts

Available data from the city for 10 years showed an annual average of 74,933.5kg (82.6 tons). This amount could serve as secondary materials for the three buildings. Students were required to select a possible material for their south-facing shade walls. Data for the declared unit of a selected wall was used to calculate equivalent GWP for alternate recycled steel. The resulting environmental impacts showed that 50% of the GWP could be reduced by reusing recycled steel as secondary materials for panels in the south-facing building envelopes.

CONCLUSION

The ability of VR sessions to improve sustainability-focused design sessions is comparable to results from previous studies. The results of this study demonstrate that VR sessions of approximately 5 minutes long are helpful in communicating spatial understanding and encourage participation of students. Students described the VR sessions as new, innovative and interesting. The materials selected to design exterior shading wall from the EC3 tool was compared recycled steel from the city and findings showed that 50% of the global warming potential could be reduced when recycled material is used. This study shows that technology could improve circularity education. Enscape software provides fast and interesting user experience of BIM to VR workflow. Further applications of VR in circularity are needed especially for the use of evaluating more building elements.

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American Squalor: A Case Study in Combating Low-Quality Housing Construction

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ABSTRACT: Located in Northwest Arkansas, the City of Fayetteville is experiencing rapid population growth, resulting in increased housing development in denser urban areas. Often this housing is characterized by inappropriate materials, faulty design and construction practices, and lack of consideration for building lifespan or performance. These factors lead to rapid degradation of new construction, rendering new units incapable of addressing long-term housing demands. This paper provides context for Northwest Arkansas' current housing demands and impacts of attempts to respond to this demand with new supply. It presents a Case Study, couched in this context, of a regionally common building in typology (multi-unit housing) and structure (pre-engineered light wood framing), and it identifies the units' design, construction, and material flaws that led to its degradation. Further, it documents the implementation of a solution that addresses immediate deficiencies while proposing broader application of lasting, sustainable material applications. The production and consumption of low-quality, if efficient, materials systems for lagging housing supply is a consistent narrative thread through US history. That said, the current urgency of the housing crisis is uniquely exacerbated by the paired exigencies of population growth and climate change. More than ever, solutions are needed that efficiently meet demand while ameliorating the pressures wrought by a changing climate and swelling population.

KEYWORDS: Housing, Construction, Commodities, Biogenic Materials

INTRODUCTION

The City of Fayetteville, a typical mid-sized city located in Northwest Arkansas, has seen sustained population growth that continually exceeds available housing, driving up costs and disproportionally affecting the most marginalized and vulnerable groups. While the City's established goals support development of affordable housing, these efforts are hampered by failures in design, construction, and material systems. This paper expands on current responses to housing demands in Northwest Arkansas and presents a Case Study that highlights impacts of rapid, low-quality construction and proposes a solution that addresses issues of quality in American housing development.

Urban housing crises are legislated and financed, perhaps rightly, through an arithmetic lens: units of housing are added, subtracting from units of demand. But there are casualties of this reductive viewpoint; construction quality and sustainability agendas are occluded. The increased prioritization of affordability directly translates to low construction costs which are exacerbated by high material costs, labor shortages, and regulatory oversight. The result is a low initial investment that leaves little margin for design considerations and materials that are aligned with climatic concerns, labor skills sets, and regional resources. Lack of consideration for building lifespan leads to the deployment of ill-suited materials systems whose poor performance renders new units incapable of addressing long-term housing demands. Additionally, low-initial investment undermines a pillar of sustainability, reducing consumption through longevity, and causes rapid degradation creating unsafe living conditions. These causalities and effects of low-quality construction are outlined in the Case Study of a housing unit within a 2014 development, identifying design, construction, and material flaws that led to its degradation. Further, it documents the implementation of a solution that addresses immediate deficiencies while proposing broader application of lasting, sustainable material systems. What the case study proposes is a wholesale reconsideration of envelope materials that better considers the role of designers, the skillsets of builders, the regional availability of materials, and the rights of owners and occupants.

The case study residence is regionally common in typology (multi-unit housing) and structure (pre-engineered light wood framing). Its cementitious cladding systems, integral sheathing, and hydrocarbon-based moisture and thermal barriers are also characteristic of contemporary regional housing construction. Its exterior expression is that of trustworthy cladding types: stucco, lap siding, and brick masonry. What lurked behind the façade was a staggering failure of design and construction stemming from the prescribed materials systems. This paper will document the failures of this structure to both maintain its own constitution and to satisfy its impetus and primary charge – providing housing to meet rapacious demand.

1.0 CONTEXT: THE HOUSING DEMANDS AND SUPPLY OF NORTHWEST ARKANSAS

1.1 The need for housing

Like many metropolitan areas in the United States, Northwest Arkansas is experiencing sustained population growth. As is typical in mid-sized cities, the growth of the City of Fayetteville and surrounding region continually

exceeds available housing units, driving up costs and disproportionally affecting the most marginalized and vulnerable groups. While the City's established goals support development of affordable housing and limiting suburban sprawl, these efforts are hampered by failures in design, construction, and material systems, reversing positive effects of new housing developments.

The population growth of Northwest Arkansas, a region consisting of Washington, Benton, and Madison Counties, has recently made the region the "nation's 100th largest metropolitan area" (Northwest Arkansas Council 2023). With the population increasing by approximately 36 people per day, the Northwest Arkansas Council (n.d.) finds "the region needs to add 2,900 housing units a year" to keep up with demand. With only 1,400 housing units built between 2010 and 2016, Northwest Arkansas has added less than one housing unit for every 1.5 households in the area (Northwest Arkansas Council n.d.). The growth in population and lag in housing construction has exacerbated housing shortages by increasing demand and, therefore, increasing costs of both home sale prices and rent.

Adding to the complexity of Northwest Arkansas' housing situation are economic factors. While 11% of the population of Northwest Arkansas are below the Federal Poverty Level, an additional 30% are below the ALICE threshold (United for Alice 2024). ALICE – Asset Limited, Income Constrained, Employed – accounts for households above the Federal Poverty Level but unable to achieve financial stability, being forced to choose between paying for necessities such as housing, childcare, or food. To accommodate the 41% of households in Northwest Arkansas below the ALICE threshold, "the region needs half of all new housing units to serve families that make less than $78,000 a year" (United for Alice 2024, Northwest Arkansas Council n.d.).

As found in the National Low Income Housing Coalition's (2023) *Out of Reach 2023* report, "the gap between wages and housing costs is largest for people of color." With the growth of Northwest Arkansas' population largely attributed to tens of thousands of incoming immigrants from El Salvador, the Marshall Islands, Mexico, and India finding work in the region's booming industries, these populations are greatly impacted by the region's need for affordable housing (Jordan 2021). Through a series of comprehensive plans, the City of Fayetteville, in Washington County has established six goals that address strategies for healthy, sustainable growth of the City. In 2018, the City 2040 Plan updated these goals with a particular focus on housing due to increased demand. In reference to the City 2040 Plan, the City explains:

> …[W]ith the population of Washington County forecast to reach more than 500,000 by 2050 (from approximately 240,000 today), the city will continue to grow. To accommodate this growth, the City is looking at ways we can encourage the development of additional, affordable housing for new residents…. (City of Fayetteville n.d.)

In addition to establishing goals within the City 2040 Plan, the City of Fayetteville (n.d.) completed a survey with responses from over 900 residents, soliciting feedback specifically focused on housing. Within that survey, 55% of respondents disagree that there are enough housing options with the city.

1.2. Impacts of rapid development

As a response to mitigate housing shortages and increase affordable options in the City of Fayetteville and surrounding region, housing development has increased. However, the need to construct low-cost housing within short timeframes establishes conflicting priorities. The downward pressure of housing costs, coupled with an amalgamation of high commodity prices, high labor rates, and rapidity of construction, incentivize pursuit of progressively cheaper construction resulting in low-quality housing. Most new housing construction, especially in urban areas, is initiated by developers. Their pro forma driven approach makes cost the number one determinant of project viability.

> It's no secret that the price of new homes is increasingly out of reach for many Americans. Every year, builders are faced with unprecedented levels of new federal, state and local regulations as well as skyrocketing material costs and labor shortages. (Giannini 2020)

These factors impact project timelines and overall costs, leaving little margin for consideration of quality. Outside of their own cost-based interests, developers need to comply with guidelines and timeframes established by municipalities. Increased regulatory oversight has impacted developer's bottom lines, creating significant delays or in some cases termination of work.

In Fayetteville, several developments have paused work – in some cases for years at a time. Developments, like those seen in Figure 1, sit partially completed and exposed to the elements for months or years on end. During this time, structured and material performance is comprised, and product warranties are voided. If work resumes, previously completed work is deconstructed and materials replaced, a process that further increases labor and material costs. In the Fayetteville area, as is the case in many mid-sized cities, there has been an increase in out-of-state developers of large multi-unit housing developments. While these developers bring with them knowledge and expertise, they also lack a vested interest in the area. What results are non-site-specific and non-regional-specific developments void of contextual responses through architectural massing or material.

Despite the presence of out-of-state developers, contractors are still reliant on the skills and size of the regional workforce. Due to the pandemic and a decreased interest in manual labor, construction trades are experiencing shortages in labor.

> [L]abor shortages have been attributed as the greatest contributor to the overall construction costs of new housing units (Giannini 2020).

With labor shortages come delays, rushed timelines, and faulty construction due to a lack of skilled labor. Those willing to work despite increased time pressures and small margins are inexperienced and lack knowledge of proper installation methods.



Figure 1: Incomplete multi-family construction on indeterminate hiatus in Northwest Arkansas. While they have latent potential for completion, the low-quality materials deployed cannot withstand long-term exposure. Source: (Author 2023)

The dramatic increase in labor costs resulting from labor shortages consumes a greater percentage of overall project budgets, limiting available costs for design services and materials and causing an abandonment of sustainability goals. Design decisions inclusions of material selection are heavily regulated through the City's guidelines and based on accepted practice rather than resiliency, longevity, and regional sourcing. The dominance of integral sheathing and cementitious cladding syndicates leaves designers with little apparent choice in choosing materials systems that are matched to the climatic, ecological, and economic contexts of their region. Their proprietary assembly methods impose processes on builders who may or may not have the requisite training or know-how for their effective installation. Due to inexperienced installation practices and lack of code knowledge, contractors have the ability to void product warranties, leaving the cost burdens of faulty construction on the owners. Additionally, irremediable chemical installation processes leave owners without the right or ability to repair them.

Rapid growth of housing causes low initial investment resulting in low-quality construction and short-term lifespans of housing. Despite the desire for additional affordable housing options, of the 900 City of Fayetteville residents who responded to the survey, 43% have a less positive perception of infill housing after experiencing it in their neighborhoods (City of Fayetteville n.d.). This can be attributed to associations with low-quality, low-investment developments including non-contextual responses, delays and disturbances in construction, and use of perishable materials. A casualty of the housing crisis is overlooking the factors of quality construction that firstly, address long-term viability of development and, secondly, consider the role of housing in the carbon sequestration and use of regional materials.

1.3 Why development does not equal housing

Despite the increase in development as a response to housing shortages, completed housing units added to the market do not always reduce units of demand. Due to variations in use or issues with construction quality, not all newly developed units contribute to resolving housing shortages in the long-term. Although occupied, some housing units are used for short-term rentals, obviating their ability to contribute to available housing stock, while others see a rapid degradation due to low-quality construction and materials, rendering the units unoccupiable within a decade of completion.

In sports-centered college towns like Fayetteville, game-day houses – or second homes purchased by fans or alumni to be used during football season – and "short-term rentals are destabilizing housing markets, fueled by wealthy fans and investors" (Salerno 2023). Despite the economic benefits of short-term rentals to college town, the hotel-like use of residences increases rent and housing costs, decreases investment in neighborhoods, encourages deferred maintenance of properties, and leaves neighborhoods vacant for most of the year. To combat this, Fayetteville enacted legislation in 2021 capping Type II short-term rentals, those without a full-time resident, "at 2% of all dwelling units in the city," equating to approximately 900 units (Ryburn 2023). Despite the cap and required licenses and permits, a portion of new or recent developments meant to contribute to viable housing stock to the City were becoming short-term rentals. Seeing the increase of short-term rentals as counter to their goals, in July of 2023 the City of Fayetteville's Council lowered the cap to 475 and by December of 2023, the cap was reached (Ryburn 2023). Although the City has made progress in regulating these properties, game-day houses used by their owners and illegal short-term rentals still pose a threat to combating the housing shortage in Fayetteville.

In scenarios where development has produced the addition of housing units for Fayetteville residents, unforeseen issues resulting from incorrect construction methods and shoddy materials still may impede long-term housing gains. In Fayetteville, several developments constructed within the past ten years are nearing condemnable standards due to significant construction-related issues. Low-quality construction and inadequate installation and detailing of materials has allowed for water infiltration, comprising cladding and structural systems, inducing rot, and increases rates of decay. Seen in Figure 2, a development of 110 units completed in 2015 has visibly failing stucco and removed cladding. It is currently undergoing significant repairs, rendering some of the units unoccupiable. Another Fayetteville development completed in 2014 consists of five units, one of which is the subject of the following Case Study. Of these five units, only two are currently occupied – with the unoccupied units

consisting of a game-day house, a vacant long-term rental in between tenants, and a vacant long-term rental undergoing significant repair. Although the two occupied units are currently in use by their owners, both were also subject to notable repairs due to faulty construction, rendering the units partially unlivable for a period of time. With issues stemming from initial design and construction – including use of cementitious materials and proprietary systems, voids of warranty due to incorrect detailing, and improper installation methods – homeowners investing in these Fayetteville developments are unable to maintain their properties. Instead, they become responsible for taking on serious repairs with exorbitant costs to remedy faulty construction or allowing further degradation due to cost limitation, resulting in unusable housing stock.



Figure 2: (Left) Envelope failures of typical new, market-rate housing construction in Fayetteville, Arkansas. Even when these failures permit continued occupancy of the structure, they degrade its value potential and portend more significant failures in the future. (Right) A typical, poorly constructed housing structure undergoing invasive repairs. The rapidity of construction, coupled with low-grade materials, catalyses building failures and triggers the need for repairs. This incurs extra expense, pauses revenue generation for the development's owners, and takes an otherwise beneficial housing unit off the market. Source: (Author 2023)

2.0 CASE STUDY

2.1. Purpose

To better illustrate the central issues brought forward by this paper, a Case Study is presented. The seriousness of the housing crisis is highly visible, and, though it may not be thoroughly understood, its existence is well documented. Often presented as a statistical or broadly demographic issue, the discussion occludes the small-scale decisions and processes at its core. The purpose of this Case Study is to give a 'face to the name'; it elucidates the nuanced ways in which a single structure fails to meet its most fundamental obligations, not least of which is to provide some measure of relief from the crisis. Though the Case Study is focused on a single subject, its purpose is to provide a representative study of – and strategies for – the failures found across the region.

2.2. Case study setup

The subject of this Case Study is a fitting specimen for this task. It typifies the size, style, and level of quality found among contemporaneous housing construction in the region. The demonstrable failures of the Case Study subject are, unfortunately, also representative. These characteristics make it an apt focus of study, especially when considering that its most unique aspect is manifest in the strategies employed to mitigate its failures, providing a broadly applicable framework for its myriad peers.

The subject is a duplex (a pair of attached single-family homes) within the city limits of Fayetteville. At the time of writing, the building has been in service for just under 10 years, passing hands from several homeowners and renters. Its two units are part of a 5-unit development occupying a corner lot in a rapidly developing, highly trafficked part of the city. Each structure is three stories, wood-framed, and initially clad in various configurations of stucco (i.e., portland cement plaster), brick, and cement board.

Though they vary in size and configuration (two duplexes and one single-family unit), the three structures were built simultaneously by the same development and construction firms, employing the same framing and envelope systems. In turn, all three buildings have been subject to the same failures, and the varying actions in response provide further validation for the Case Study. One building has not been mitigated, providing a "control" for the Case Study subject. The third building went through a mitigation process, albeit one whose strategy was fundamentally different from that of the Case Study. There, only the most superficially obvious issues were addressed, and the affected building envelope components were replaced in-kind. While not serving as another unadulterated "control", this structure represents an alternative future for the Case Study subject, where less consideration led to matter-of-course strategies.

2.3. The problem

The subject house exhibited evidence of significant design and construction flaws early in its life. Symptoms included water infiltration around windows, sagging and damp interior finishes, and bulk flooding during heavy rain events. Mostly occupied by renters, occupants had neither the tenure nor investment to fully appraise the severity of the issues. For they went unmitigated until the original developer/owner sold the property to an owner-occupant.

The new owners immediately recognized that the water-based issues presenting themselves could portend more widespread, insidious failures in the building's structure and envelope. Contracting with a mitigation firm, infrared scanning revealed extensive moisture within the exterior walls. To corroborate these findings, the firm conducted selective demolition of interior finishes at critical, susceptible junctures. They removed gypsum board near window jambs and wood trim at the sills to conduct a visual inspection of the wall cavity. What they found provoked the subsequent two processes. First, large areas of gypsum board and flooring were removed to expose affected areas in the wall and floor cavities, respectively. Following this, the mitigation firm dried the cavities, removed the propagation of mold, sanitized them against further mold growth, and ran air scrubbers within the space for several days, eliminating airborne spores. Beyond reinstallation of interior finishes, what remained after stabilizing moisture and mold spread was to grapple with the compromised structure.

In assessing the structure's integrity from the interior, the extent and severity of the damage left even erudite contractors shocked. Critical studs at window edges were left rotted and friable along their length and at their bases – precisely where the walls' weight from above aggregated (Figure 3). The plywood sheathing, attached to the studs' exterior, was in some places so badly rotted that it had dissolved into flakes mounded at the bottom of wall cavities. The most deleterious, if not readily visible, damage was to the metal lath mesh, whose sole task was to support the cementitious stucco on the exterior. In places, all that remained of the lath was its imprint on the interior side of the stucco – a shadow of something long rusted away by moisture. While the stud and sheathing degradation presented existential risks for the structure, the more consequential issue was the absence of metal lath: thousands of tons of the cementitious stucco could at any moment slough off onto unsuspecting bystanders. The extent of the damage made two facts evident: that a significant amount of the structural components needed to be replaced, and that doing so would require removal of all exterior cladding.



Figure 3: Water infiltration through the cladding and windows likely occurred for the life of the building. The polyurethane insulation is largely removed in this image to expose rotting structure, but its presence would have trapped the water, encasing susceptible wood members. Blackened structural members were completely friable; the material in this image was easily crumbled by hand. Sheathing and metal lath had completely disintegrated prior to demolition of the exterior cladding, making plain both the magnitude of the issue and the dangers it presented to human health and safety. Source: (Author 2023)

Clearly, exterior cladding dependent on failing structure could not be kept in place. More, cladding dependent on structure of indeterminate solvency needed to be removed, if only to determine the status of the structure behind. The decision was made to remove all cladding from the structure, including brick veneer, stucco, and cement board. In doing so, the windows would also be removed, though they could be returned to their openings. New cladding would be installed following structural repairs, but its type and configuration would be dependent on identification of the sources for the offending failures. In effect, removal of the cladding was a forensic exercise, permitting identification of the design and constructive failures that catalyzed the damage.

From a technical standpoint, the building envelope and structure issues stemmed from a litany of detail failures. The integrated sheathing, a materials system designed to act as both structure and water-resistive barrier, proved the venue for many of these. By itself not problematic, three systemic installation errors caused widespread failures in the sheathing. For one, the nails used to attach the sheathing to the studs were universally over-driven. At each nailing point, the nail head breached the integrated sheathing's weather-resistive barrier, creating a pathway for water to reach the moisture-sensitive wood composite beyond. The building code and the manufacturer requirements indicated about 88 nails per sheet, and, with an estimated 200 sheets distributed across the structure, this error created 17,600 opportunities for water infiltration. A second failure occurred at the seams between sheathing panels, where the proprietary sealant tape was not adequately adhered, permitted more water intrusion at the panels' vulnerable edges (Huber sheathing 2023, 17-19). The third sheathing-based failure arose from the improperly installed stucco cladding. Both the building code and the manufacturer instructions expressly required

an additional layer of weather protection between the sheathing and the stucco, and this was not installed, reducing the system's effectiveness (Huber stucco 2023, 1). Moreover, the nails used to attach the stucco's metal lath were too long, fully penetrating the sheathing and creating a moisture pathway into the cavity, and they did not have a "furring" head, as required by the manufacturer, to suspend the metal lath away from the sheathing. The stucco application itself was thinner than the 3-layer, 22mm (7/8 in)-thick requirement stipulated by standards (Melander 2003, 18-22). Its thinness permitted more rapid water propagation though the assembly and greater chances of a water-logged cladding. Once there, the absorbed water had several options for penetrating the barrier (Figure 4).



Figure 4: Stucco (i.e., portland cement plaster) comprised the plurality of facade materials. Its installation did not adhere to requirements established by building code and standards, dooming the defenseless wood structure behind. In the left image, damaged sheathing is exposed beneath the stucco. Where the yellow polyurethane insulation is visible, the sheathing has completely disintegrated. Source: (Author 2023)

Outside of the sheathing and stucco, two other components enabled degradation of the structure. Extensive water infiltration around windows resulted from the lack of metal flashing at the window head. But for the stucco cladding, this might not have been such a damaging misstep; the stucco collected and channeled water to the window head, where it found pressure relief by dropping into the opening around the window. A more standard, thicker application of stucco could have prevented water propagation through material. Still, the inclusion of metal flashing would have been standard practice. Exacerbating damage from the inevitable presence of water in the cavity, polyurethane spray foam insulation within the wall cavities trapped liquid water against the interior-facing, uncoated face of the sheathing as well as the wood studs. If, as building envelope Joseph Lstiburek notes, the fundamental job of a building envelope is to 'keep the outside out and the inside in', all the failures of the sheathing, cladding, windows, and installation conspired to create the polar opposite conditions: the envelope invited the 'outside' and 'inside' to mingle somewhere between (Lstiburek 2018, 62).

Grotesque as they were, the most unsettling observation of the Case Study's technical failures was their pervasiveness. That they were so consistently expressed points to systemic issues beyond the execution of material assembly. Coordination, communication, and evaluation of limitations, among other processes undergirding the building's formation, were fundamentally absent or corrupted. Of all the parties involved in completing the building, none carry complete, unequivocal culpability. That said, systemic failures are identifiable. The architect(s) who created the construction documents did not successfully communicate passable details. Whether they were correct and not communicated, incorrect and communicated, incorrect and not communicated, critical details were not considered in construction. Regardless, this pivotal information exchange was aborted when, evidently, it was most needed: to save costs, the developers released the architects before the start of construction, arrogating the critical tasks of construction administration. The contractor's work was without oversight, and the project contained little incentive for oversight. This allowed otherwise minor issues to metastasize. For example, avoiding over-driven sheathing nails would require a simple change to a crew's nail gun settings. In the absence of that change, what would have been a minor issue recurred – 17,600 times.

Even with adequate oversight, the project's contractors were not well-positioned to create a high-quality product. Regional market forces had stretched the capacity of construction labor, adding pressure to complete the project rapidly and placing unskilled laborers in positions requiring significant skill and experience. More than that, the envelope materials systems selected for the project were as demanding of precision as they were unforgiving of error. For example, the integrated sheathing system required the use of both a proprietary seam tape and a proprietary tool to apply the tape. These narrowly defined methods, ostensibly meant to speed construction and reduce costs, pushed the contractors to the limits of their skillsets. And, as the seam tape could not be removed and re-applied, errors were irreparable without significant interruption. This characteristic, an inability to unwind installation processes, was endemic in the materials processes throughout the project. Adhesive or fluid-applied methods of sheathing tape, stucco, spray insulation, and brick veneer, among others, could not be corrected nor modified once stuck, hardened, or cured.

The same 'one-way street' characteristic that colored the contractors' work precipitated the need for complete demolition of the cladding and sheathing to make structural repairs. The installed systems did not permit temporary

removal for minor investigations, let alone re-installation after repair. Because of this, nearly 76 m^3 (about 100 cubic yards) of construction waste was generated. That said, “waste” should not be reduced to an anonymous volume of material. It was the wasted labor of many hands who dedicated some portion of their lives to the project’s realization. It was the wasted liquidity of capital and resources that could no longer be leveraged for housing. And it was the wasted embodiment of greenhouse gasses generated in the materials’ manufacture and logistics. Still, while this evaluation was an indictment of the decision-making culminating in extensive demolition, it also served as a roadmap for developing a strategy to advance the project.

2.4. The solution

Ameliorating the building structure and façade could not include a re-introduction of the initial materials systems and processes, lest the building (and its owners) suffer the same consequences in the future. Instead, identification of the governing constraints made clear by the initial systems provided a framework for four sequential, strategic objectives. First, new envelope components would be solid-state, with no fluid applications and limited adhesives. Intending to inoculate the building of the conditions present in its initial façade, solid materials would permit repair and reconfiguration of the envelope both during construction and throughout the life of the building. The second objective was a corollary of the first. The irony of solid-state envelope materials is that they enable the flow of fluids by creating well-defined voids. In contrast with the initial cladding, the new cladding solution would be a rainscreen system, permitting liquid water and air to flow in- and out of a defined air space. Per typical rainscreen performance, it would prevent water from pooling and give it an opportunity to escape or dry out.

The third objective also related to the first. To reduce the already prodigious carbon footprint of the building (owing mostly to the waste material), the cladding system would avoid a hydrocarbon-based material palette in favor of biogenic materials. This happens as a matter of course; the flexible plastics and mutable cement of the initial cladding were hydrocarbon-based. The new solution would include wood boards over rigid furring. Furthering the embodied carbon agenda, the wood would be specified as Southern Yellow Pine, a regionally available species. And, to avoid the introduction of harmful chemicals at sites of production or construction, the wood would be treated with a thermal modification process in lieu of the chemical-heavy pressure treatment process.



Figure 5: On the left, the non-adhesive, weather-resistive barrier and furring await coverage by the wood rainscreen. On the right, a corner perspective image of the completed building. Source: (Author 2023)

The fourth objective further capitalized on the previous three objectives and was based on a realistic assessment of labor limitations. Where the initial cladding system had three distinct material systems (stucco, cement board, brick veneer), the new solution would employ one: a vertically oriented wood rainscreen. The impetus for this objective was found in envelope failures based on complicated installation processes. The three-material initial cladding required divergent skilled labor groups, clear communication among these groups, and careful detailing where the materials interfaced. A single material strategy obviated these requirements, permitting the installation team to focus on achieving quality with fewer complications and decision points (i.e., opportunities for failure).

The established strategic objectives yielded a singular, feasible solution that met the performative and constructive imperatives of the project. Following cladding demolition and structural stabilization, new, non-integrated sheathing was installed. Over this, a vapor-permeable, non-adhesive weather resistive barrier was installed, followed by horizontal cellular furring strips. Thermally-modified, 19mm x 140mm (nominal 1x6), Southern Yellow Pine boards were then attached in a vertical orientation using stainless steel screws. The simplicity of this installation process provided two significant benefits for the project: the system could be accurately installed regardless of the laborer’s skill level, and the system could be deconstructed with the same level of skill and simplicity. Most importantly, the new solution acutely avoided the sources of failure found in the initial scheme, ensuring that the catastrophic damage wrought by that flawed system could not recur.

CONCLUSION

The housing crisis in Northwest Arkansas is the result of several converging factors. Housing quality, typically suppressed by labor costs, is an often-overlooked driver in reducing housing availability, and it is at its most severe when systemic building failures remove units from the housing pool. That said, the present scenario is not without precedent. Ever the economy-driven society, the history of construction in the US is a narrative of suppressing costs

to meet demand, where social, ecological, and qualitative concerns are collaterals. What makes this moment in history different are the global, self-perpetuating exigencies of population growth and climate change. We can scarcely afford to build things that won't last. Still, an insidious, positive feedback loop continues to push quality down, exacerbating issues of climate change and providing scant solutions to it. It is a wicked problem, and blame can no more be cast on consumers than it can the architects, builders, product suppliers, or authorities that have greased the tracks of this downward slide. That said, because of their central position in the formation of buildings, it is incumbent on architects to develop and provide solutions to abate the issues plaguing housing in America.

What is presented in the Case Study is not a broad solution but one that intentionally targets a blind spot in efforts to increase housing affordability. And it is not a generically "green" approach to mitigating climate impacts, but rather one that seeks solutions based in the realities of material and labor availability. The materials systems deployed enable a resilient structure couched in the sentiments of *Design for Deconstruction* and *Right to Repair*, methods for increasing the useful life of the structure. Finally, it posits that the uniquely American struggle for efficient construction can be leveraged towards housing and climate strategies, given the will to imagine longevity as a goal.

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Verification of the Energy Attributes of a Biochromic Facade through Real-time Measurements

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ABSTRACT: Microalgae facades can significantly impact a building's energy consumption and carbon neutrality. This particular facade achieves this effect through various mechanisms, including dynamic shading efficacy, winter solar gain, dynamic visual light transmission, carbon sequestration through photosynthesis, and the transfer of produced oxygen to indoor space. While numerous smart facades have been introduced in the contemporary era, the imperative to attain zero-carbon buildings has intensified the quest for nature based, sustainable solutions characterized by minimal carbon production and real time carbon sink throughout their life cycles. This paper aims to assess the potential for reducing building energy consumption by examining the influence of microalgae facades on Solar Heat Gain Coefficient (SHGC) and Visual Light Transmission (VLT).

The research employs a combination of experimental and simulation approaches to facilitate comprehensive result comparisons. Microalgae façade samples were prepared at four distinct cell densities (25%, 50%, 75%, and 100%) to examine the density's impact on SHGC and VLT. Furthermore, the study undertakes a comparative analysis of energy consumption of a reference building and a microalgae building across diverse climates. This comparison is conducted using conventional glazing according to ASHRAE 90.1 and microalgae facades with varying cell densities, contributing to a nuanced understanding of their respective energy efficiency implications. The results indicate that cell density and thickness of microalgae facades can play a key role in SHGC and VLT. Therefore, microalgae can act as a façade with dynamic U-value and VLT depending on different climate zones. The results indicate that almost in all climates integrating microalgae façade can reduce the energy consumption by 4% to 12%.

KEYWORDS: microalgae façade, decarbonization, energy efficiency, dynamic solar heat gain, visual light transmission.

INTRODUCTION

The existence of various crises in the field of global warming, ozone layer perforation, and the excessive increase in greenhouse gas emissions has prompted a reevaluation of various aspects across sectors (Falkowski, et al. 2000) (Pittock 2009). One crucial aspect that should be considered in every sector is energy consumption, as 80% of greenhouse gas emissions are linked to the energy sector [3]. Buildings can play a pivotal role in reducing energy consumption and environmental problems. Buildings in the United States are responsible for approximately 40% of CO2 emissions, 40% of energy consumption, and 70% of electricity use (EIA 2017) (Nejat, et al. 2015) (Saxton 2019).

Despite efforts at different levels to derive energy from renewable sources, only 20% of electricity production in the United States utilizes renewable sources, and fossil fuels still hold a significant share in electricity production (Office of Energy Efficiency & renewable Energy 2023). Therefore, finding sustainable solutions to reduce energy consumption and generate clean energy in the building sector becomes imperative.
One such solution is the use of microalgae, whose applications are expanding across different sectors due to their unique properties. Microalgae can serve as an environmentally friendly source of food, energy, and animal feed [8], providing possibilities for biofuel production (Sharma, et al. 2012) (Coppo, et al. 2014) (Shurtz, Wood and Quinn 2017).

Feasibly, a bioreactor facade within a building can be established through the integration of a microalgae facade. Such integration proves considerably more versatile and sustainable compared to conventional facades. This innovative approach not only reduces carbon dioxide emissions but also enhances indoor air quality by leveraging the oxygen produced during photosynthesis. Additionally, the flexibility to adjust the microalgae cell density based on seasonal variations and the demand for solar heat gain regulations allows dynamic control over shading levels, thereby aiding in diminishing both cooling and heating loads. Moreover, microalgae facades exhibit the capacity to generate biomass and thermal energy through harnessing sunlight and contribute to a positive influence on the building's acoustic environment (Talaei, et al. 2022) (Pagliolico, et al. 2019).

1.0 LITERATURE REVIEW

Numerous articles have explored the utilization of microalgae facades in buildings, investigating their impact on diverse metrics such as energy consumption, indoor air quality, thermal comfort, solar heat gain, and other relevant parameters. Kim (Kim 2013) investigated the impact of microalgae facades on multiple parameters, including

thermal performance, daylighting, and structural aspects. This research, employing simulations and experiments, took place in North Carolina. The findings revealed a substantial positive effect, indicating an enhancement in the building's thermal and daylight performance through the incorporation of this facade type. Based on the results, the microalgae facade's U-factor is comparable to that of an insulated glass unit (IGU) with a low-e coating. Moreover, the vision zone can illuminate the perimeter zone of interior space without using any artificial lighting.

Elnokaly et al. (Elnokaly and Keeling 2016) conducted an additional study involving experimentation to investigate the impact of microalgae density and shading in Lincoln, United States. The results of this experiment revealed that an increase in microalgae density led to a decrease in light penetration and internal luminance. Furthermore, the study observed a weak correlation between culture density and shading efficiency. Sadra et al. (Sadra and Vicente 2016) in Madrid, Spain, conducted research on the effects of employing a specific microalgae profile using simulation and theoretical methods. According to the findings of this study, the microalgae facade has the potential to significantly reduce energy consumption. Araji et al. (Araji and Shahid 2018) investigated factors such as shape, panel orientation, and other relevant parameters to enhance the performance of integrated flat panels containing microalgae. A comparative analysis between aspect ratios of 1:8 and 1:1 revealed that a building with a 1:8 aspect ratio has a higher potential to achieve a net-zero energy building rather than a 1:1 ratio building by 40.31% due to energy saving potential. Additionally, the photobioreactor (PBR) with a 75° panel orientation demonstrated superior energy efficiency compared to its counterpart with a 90° orientation.

Shading devices have a positive impact on energy consumption. A study by Martokusumo et al. (Martokusumo, et al. 2017) compared temperature differences indoors and outdoors by comparing façade brise soleil, a horizontally fixed shading device, and algae PBR. They conducted this study in Indonesia using experiments and simulations. The results indicate that the PBR facade has the highest temperature difference (6.447°C) while the algae bioreactor can reduce daylight by more than 90%. The consumption of energy cooling (district cooling) for the building integrated algae PBR is less than the energy consumption of the façade applying brise soleil and horizontally fixed shading device.

The integration of biomass production with the building offers significant advantages. In a theoretical exploration and simulation conducted by Provost et al. (Pruvost, et al. 2016), the study delved into the impact of PBR inclination, light interception, and various parameters on biomass productivity and energy consumption for generating 1 ton of biomass in Nantes, France under six distinct conditions (varying based on inclination degree, thermal symbiosis efficiency, PBR thickness, and night mixing). The results indicate that the symbiotic relationship between the microalgae bioreactor and the building façade can substantially reduce the energy requirements for microalgal culture compared to standalone solar PBRs. In comparison to PBR façades lacking thermal symbiosis and those with 50% thermal symbiosis, PBR façades with 100% symbiosis yield require less energy for the annual production of one ton of biomass. Additionally, these PBR façades with 100% symbiosis yield do not undergo night mixing. Furthermore, the heat generated by the microalgae façade can be effectively utilized within interior spaces. According to a study conducted by Kerner et al. (Kerner, et al. 2019), 80% of the heat produced by the microalgae façade can be harnessed for heating purposes in interior spaces.

Despite the existing research in the field of microalgae, further investigation is needed to comprehensively study the impact of various biological and architectural variables on building energy consumption. To enhance and broaden the utilization of microalgae facades, it is imperative to assess the efficiency and performance of this architectural feature under diverse conditions by examining various parameters. These parameters encompass design aspects like form, orientation, and thickness, as well as factors related to microalgae, including species, density, and environmental conditions such as climate and test location.

2.0 MEASUREMENTS OF ENERGY ATTRIBUTES

SHGC (Solar Heat Gain Coefficient) and VLT (Visible Light Transmittance) are two important energy attributes that impact heating, cooling, and lighting loads. To estimate SHGC and VLT, the algae samples were installed on a black chamber facing a south orientation (Figure 1). The algae samples were 1ft by 1ft flat panels with four varying algae cavity thicknesses and four different algae cell concentrations. The initial dense culture was named "pseudo 100%" to indicate 100% algae density. In the "pseudo 75%" culture, 25% of the initial algae was replaced with water. Similarly, in the "pseudo 50%" culture, 50% of the initial algae was replaced with water. Lastly, in the "pseudo 25%" culture, 75% of the initial algae was replaced with water.

The SHGC and VLT data were measured on a clear summer day on July 29, 2023 by assessing the radiation transmittance through the algae samples. The measurements were conducted using a pyranometer (Apogee SP510), photometer (Apogee SE421), and quantum meter (Apogee SQ521). A set of pyranometer, photometer, and quantum meter was installed on top of the chamber and measured incoming sunlight. Another set of sensors was installed inside the chamber behind the algae samples and measured the transmitted sunlight through them. The pyranometer, is commonly used to analyze the absorption and transmission of light in range of 385 nm to 2105 nm. This device determined the algae samples. The quantum meter measures photosynthetic photon flux density in range of 389 to 692 nm. The device assessed how much solar energy is transmitted through the algae samples. The photometer is specifically designed to measure light intensity from 0-150,000lux. This instrument provided daylight penetration through the amount of photosynthetically active radiation (PAR) absorbed by the algae samples at different concentrations. PAR is directly related to plant growth and therefore, only SHGC and VLT were presented in this paper.

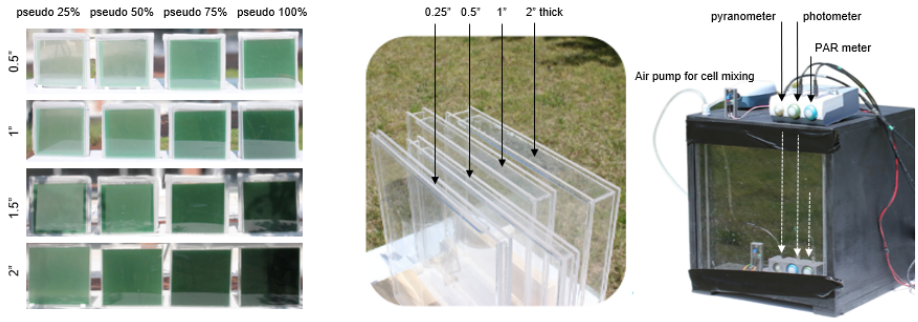


Figure 1: SHGC and VLT Experiment Set-up Consisting of the Algae Façade Samples, a Testing Chamber, and Data Measuring Sensors. Source: (Kyoung Hee Kim 2023).

Table 1 provides a comprehensive overview of measurements conducted across various testing scenarios. The data reveals a clear correlation between algae cell densities and both SHGC and VLT. The microalgae medium with the lowest cell concentration exhibits the highest SHGC and VLT values, while the pseudo 100% microalgae culture shows the lowest values. The SHGC demonstrates non-linear reduction as algae density increases across different thicknesses. The 2-inch cavity exhibits less sensitivity to SHGC changes for different microalgae densities, particularly in the high concentration region, when compared to other thicknesses. The influence of microalgae density on VLT also showed a clear correlation. The reduction in density from 100% to 25% results in substantial VLT.

In parallel with SHGC, the 2-inch cavity demonstrates reduced sensitivity in VLT changes for microalgae density than other thicknesses. Additionally, the data reveals a clear correlation between algae cavity thickness and both SHGC and VLT. As the thickness of the algae cavity increased from 0. 5 inches to 2 inches, both SHGC and VLT decreased. Within the range of 0. 5 to 1. 5 inches, both SHGC and VLT exhibit higher sensitivity to changes in VLT compared to the 2-inch thickness. The light-to-heat gain ratio (VLT/SGHC) can be used to assess the efficiency of a glazing system in blocking summer solar gains while maximizing daylight penetration.

A higher light-to-heat gain ratio indicates better energy efficiency. As the algae cavity thickness decreases, the light-to-heat gain ratio increases. For high cell concentration, the 2-inch thickness exhibited reduced daylight penetration. This characteristic is particularly beneficial for spaces that necessitate different levels of privacy or where glare negatively affects productivity and well-being.

Table 1: Experimental Results: Investigating the Influence of Cavity Thickness and Microalgae Density on SHGC and VLT. Source: (Authors 2023).

Metrics	*Pseudo cell density*	*Thickness*			
		0.5 inch	*1 inch*	*1.5 inches*	*2 inches*
SHGC	*25%-Microalgae*	0.71	0.60	0.51	0.40
	50-Microalgae	0.63	0.47	0.37	0.28
	75-Microalgae	0.48	0.36	0.30	0.21
	100-Microalgae	0.45	0.34	0.29	0.10
	Water	0.73	0.80	0.82	0.86
VLT	*25%-Microalgae*	0.64	0.55	0.39	0.96
	50-Microalgae	0.46	0.30	0.16	0.23
	75-Microalgae	0.27	0.16	0.06	0.06
	100-Microalgae	0.185	0.086	0.028	0.005
	Water	0.73	0.80	0.82	0.96

Figure 2 visually represents the effective SHGC and VLT across various densities and cavity thicknesses. Additionally, polynomial trendlines are incorporated into the figure. The data points allowed us to establish the relationships between solar gain, daylight penetration, and cell density for different cavity thicknesses. The inclusion of these mathematical relationships enhances our understanding of how SHGC and VLT varies with microalgae density across different cavity thicknesses, providing valuable insights into the nuanced interplay between these factors.

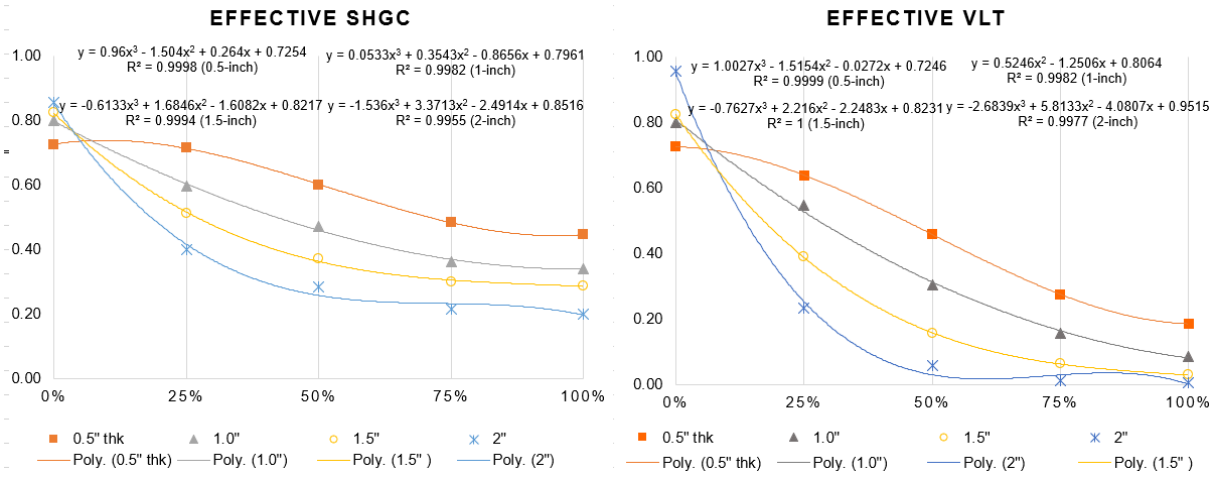


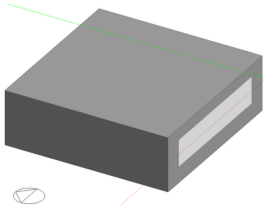
Figure 2: Correlation between microalgae density and effective SHGC (left) and VLT (right). Source: (Authors 2023).

3.0 ENERGY SIMULATION

The impact of using a microalgae facade was investigated in nine different cities, including Miami, Houston, Los Angeles, Charlotte, New York, Boston, Minneapolis, Fargo, and Fairbanks. These cities represent different climate zones in accordance with ASHRAE 90.1. The comparison was conducted through DesignBuilder software (Designbuilder n.d.). DesignBuilder is a comprehensive software tool employed for the meticulous modeling of diverse facets within the realm of building design through the EnergyPlus engine. It adeptly facilitates the dynamic simulation of energy consumption across various building typologies. This simulation encompasses heating, cooling, lighting, appliances, domestic hot water, and other performance metrics. DesignBuilder was harnessed to model the intricate physics of the building, incorporating considerations such as materials, architectural features, as well as heating and cooling systems and lighting systems (Eisabegloo, Haghshenas and Borzoui 2016). Moreover, DesignBuilder exhibits proficiency in Computational Fluid Dynamics (CFD) modeling and can accurately compute lighting rates within a given spatial context. Leveraging climatic data files, the software excels in the precise calculation of energy-related parameters, encompassing energy reception, wastage, and consumption, tailored to the unique climatic conditions of the site (Eisabegloo, Haghshenas and Borzoui 2016). An exemplary attribute of the DesignBuilder software lies in its user-friendly interface, characterized by an excellent Graphical User Interface (GUI). Noteworthy is the software's self-sufficiency, as it operates autonomously without necessitating additional software dependencies. This attribute enhances the accessibility and usability of DesignBuilder, making it a versatile and efficient tool for architects, engineers, and researchers engaged in the intricate domain of building design and energy simulation (Eisabegloo, Haghshenas and Borzoui 2016).

The primary objective of this investigation was to evaluate the energy performance of a microalgae facade in comparison to a glass window that is in compliance with standards, taking into account different climate zones. The study used a single-zone space with dimensions of 30 feet in width, 30 feet in length, and 10 feet in height. The building had a Window to Wall Ratio (WWR) of 40% on the south-facing facade only. The remaining building envelopes, including the east, west, and north facades, as well as the floors, were set as adiabatic, meaning no energy flows were allowed except through the south facade. The building schedule followed an office schedule, which calculated the energy consumption associated with office activities. The HVAC system was assigned with variable-air-volume (VAV) terminal units, and the lighting power density was set at 0. 7W/sq. ft in accordance with ASHRAE 90. 1 standard. Table 2 summarizes the simulation setup and parametric variables. The parametric variables included nine different cities and eight different SHGCs, which represent various algae cell concentrations.

Table 2: Simulation Set-up and Parametric Analysis Variables. Source: (Authors 2023)

	Microalgae building	*Reference building per ASHRAE 90.1 standards*
Climate zones in accordance with ASHRAE 90.1	1A_Miami, FL (very hot humid) 2A_Houston, TX (hot humid) 3C_Los Angeles, CA (warm marine) 3A_Charlotte, NC (warm humid) 4A_ New York, NY (mixed humid) 5A_Boston, MA (cool humid) 6A_Minneapolis, MN (cold humid) 7_Fargo, ND (very cold) 8_Fairbanks, _AK (subarctic)	
% WWR	40%	
Window attributes	SHGC-0.1, U-0.48	1AB_ SHGC-0.23, U-0.5

	SHGC-0.2, U-0.48 SHGC-0.3, U-0.48 SHGC-0.4, U-0.48 SHGC-0.5, U-0.48 SHGC-0.6, U-0.48 SHGC-0.7, U-0.48 SHGC-0.8, U-0.48	2AB_ SHGC-0.25, U-0.45 3ABC_SHGC-0.25, U-0.42 4ABC_ SHGC-0.36, U-0.36 5AB_ SHGC-0.38, U-0.36 6AB_ SHGC-0.38, U-0.34 7_ SHGC-0.4, U-0.29 8_ SHGC-0.4, U-0.26
Other simulation settings	Gross floor area: 900ft^2 Operation schedule: office Other enclosure requirements, lighting & HVAC & plug load requirements per ASHRAE 90.1 standard	

The results of the simulation are presented in Table 2. The highlighted numerical values in this analysis correspond to the glazing recommendations outlined by ASHRAE 90.1 for distinct climate zones. These simulations aim to provide insights into the energy efficiency of dynamic microalgae facades in diverse climatic contexts.

The results indicated that microalgae facades yield a significant reduction in energy consumption, ranging from 4% to 12%, across various climates compared to counterpart window systems. The highest reduction in energy consumption was observed in Miami (very hot and humid; 1322.92 kWh savings), followed by Minneapolis (cold and humid; 1199.24 kWh savings), Boston (cool and humid; 1141.80 kWh savings), New York (mixed and humid; 1082.31 kWh savings), Charlotte (warm and humid; 1007.87 kWh savings), Houston (hot and dry; 886.25 kWh savings), and Los Angeles (warm and marine; 378.94 kWh savings). The most substantial potential for energy savings was identified in the Miami climate (Very hot and humid). The microalgae facades demonstrated an annual energy consumption of 19682.94 kWh, whereas the counterpart building consumed 20991.22 kWh. As a result, the microalgae facades achieved a 7% energy savings (1322.92 kWh) due to their lower SHGC throughout the seasons. In mixed climate zones, the energy consumption for the reference building with ASHRAE windows in New York was calculated to be 10393.47 kWh, while the microalgae building had an annual energy consumption of 9311.45 kWh, which can be attributed to the dynamic adaptability of microalgae facades in regulating solar gains based on seasonal variations. This positive impact is prevalent in most climates, excluding Fairbanks, where the U-factor plays an important role in heating dominant. Specifically, during the heating dominant seasons in Fairbanks (January through April and September through December), the microalgae facade with a U-value of 0. 48 and SHGC of 0. 8 had a higher energy consumption of 11405.15 kWh compared to the referenced window with a U-value of 0. 26 and SHGC of 0. 4, which has an energy consumption of 11174.21 kWh. This results in a 2% increase (230.94 kWh) in energy consumption due to the microalgae facades' ability to maximize winter solar gain. During the cooling seasons (May through August), the microalgae window with a U-value of 0. 48 and dynamic SHGC has a lower energy consumption of 2350.14 kWh compared to the reference window with an energy consumption of 2402.60 kWh. This results in a 2% energy savings (51.58 kWh) due to the microalgae window's ability to block summer heat gain.

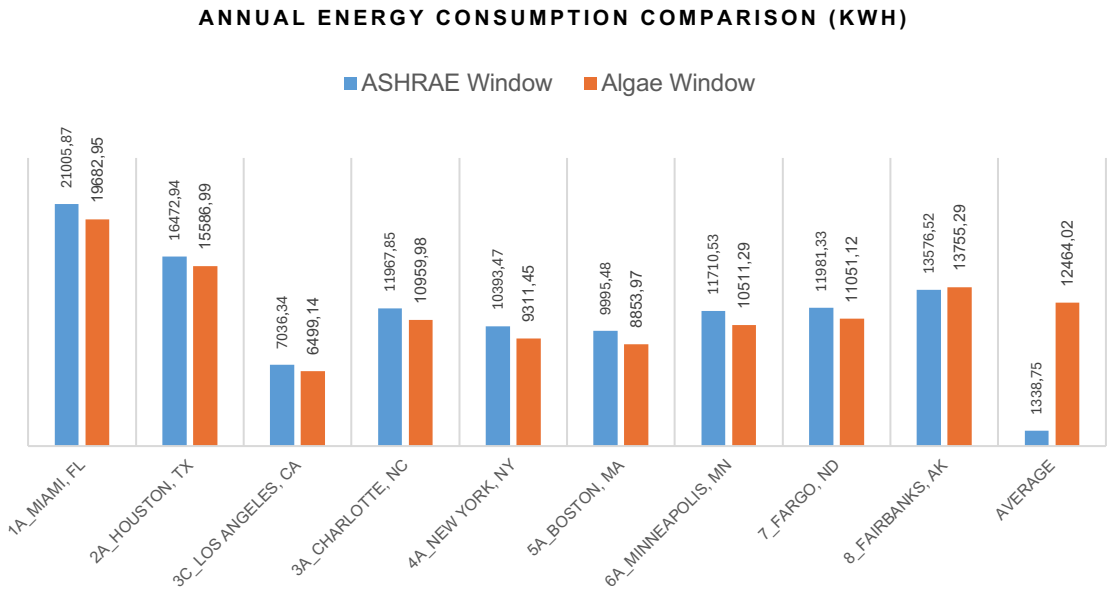


Figure 3: Simulation results: Investigating the influence of using microalgae façade on energy consumption (kWh) in different cities. Source: (Authors 2023).

CONCLUSION

A microalgae facade, with its unique features and positive impact on energy consumption and greenhouse gas reduction, as well as its ability to provide shading based on specific needs in climate conditions, is gaining

prominence and deserves extensive research. This study aims to investigate the influence of various parameters and conditions on microalgae facades. The research involved measuring the effect of microalgae density and thickness on Solar Heat Gain Coefficient (SHGC) and Visible Light Transmittance (VLT) through various tests and sensors. Conducted in Charlotte, North Carolina on July 29, 2023, the study also utilized simulation techniques to compare the energy consumption of a building enclosed with a microalgae facade to a reference building with identical specifications but featuring conventional glazing in compliance with ASRHAE 90.1 requirements. The study building was 30 feet by 30 feet building with a height of 10 feet, having 40% openings on the south façade only.

Results revealed that altering microalgae density from 100% to 25% led to changes in SHGC and VLT, consequently impacting on the building's energy consumption. The substantial difference in SHGC values highlights the dynamic nature of this architectural feature, allowing for adjustments according to the building's requirements by manipulating microalgae density. Comparative analysis of energy consumption between a building using a microalgae facade and one using ASRHAE 90.1 glazing demonstrates that, in almost all climates, the use of a microalgae facade results in a reduction in energy consumption. The microalgae facade, particularly with dynamic SHGC, exhibited a 6% to 12% decrease in energy consumption compared to a building using ASHRAE-recommended glazing across the majority of the climate zones studied. These findings underscore the potential of microalgae facades to contribute to sustainable and energy-efficient building practices.

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(Pre)casting Architectural Concrete: Search for a Design Guide for Techniques, Resources, and Advancements of Architectural Precast Concrete

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ABSTRACT: The integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) has revolutionized the fabrication of custom architectural components, particularly in the realm of custom architectural precast concrete. This paper delves into the multifaceted world of architectural precast concrete, by doing three things. First, it identifies the manufacturing variables for architectural precast. These include but are not limited to mix design, manufacturing processes, shipping and erection considerations, mold materials and configurations, and the role of CNC equipment in mold making. Second, it lists case studies of prominent architecture projects that make notable use of architectural precast concrete. The case studies include the Perot Museum of Nature and Science, Museum of Civilizations of Europe and the Mediterranean (MuCEM), and The Broad. Third, this paper provides a narrative-style literature review of book publications that feature architectural precast. The goal of this paper is to create the framework for a published guide for architects that demonstrates what is possible when designing with architectural precast. With over 175 examples gathered from various sources spanning the last two decades, this paper offers a comprehensive overview of the design and fabrication of custom architectural precast concrete elements.

KEYWORDS: architectural precast, concrete, custom

INTRODUCTION

The processes of computer-aided design (CAD) and computer-aided manufacturing (CAM) have allowed for the design and fabrication of complex surface articulations for buildings. The combination of computer numeric controlled (CNC) equipment's capabilities and architects' desire to design unique buildings, has led to contemporary projects with bespoke cladding elements, which requires architects to collaborate with industry leaders for the design and fabrication of custom components. The precast concrete industry, particularly those that produce architectural precast, have responded to this challenge by developing processes to produce custom precast elements.

Precast concrete is manufactured at off-site facilities and delivered, typically by truck, to the building site. Precast elements are structural, architectural, or a combination of both. Structural precast elements—such as double tees, beams, and columns—are primarily used for the building's vertical or lateral loads. Since these members are principally designed to fulfill a structural role, their surfaces may not be pristine and may be pitted by small air pockets or bug holes. In contrast, architectural precast's primary role is as the cladding or enclosure system for a building, and its surface quality is significantly better than that of structural precast. When forming architectural precast, manufacturers minimize bug holes and architects often specify concrete surfaces with specialty aggregates, integral color, and post-production finishing (e.g. sand blasting, acid washing, or polishing). Sometimes precast elements may be both structural and architectural, supporting the building loads while having the surface quality required for architectural precast.

Architectural precast manufacturers can accommodate different types of concrete (e.g. traditional, Portland cement-based concrete versus ultra-high performance concrete (UHPC)) with custom molds, specifically built by the precast manufacturer for a particular project. For architectural precast elements, the design and fabrication team consider the manufacturing process, transportation limitations, joints between panels, mold materials (e.g. wood, steel, rubber) and fabrication (e.g. CNC-milled versus hand-built), mold durability and costs, mold configuration (e.g. tessellated modules versus interchangeable plugs), and erection costs and methods.

This paper seeks to do three things. First, it establishes and provides an overview of the variables associated with precast concrete. Second, it provides a list of notable architectural projects that have prominent use of custom architectural precast to serve as case studies. Our examples are limited to those that have been completed in the last twenty years and includes the Perot Museum of Nature and Science by Morphosis, Museum of Civilizations of Europe and the Mediterranean (MuCEM) by Rudy Ricciotti, and The Broad by Diller Scofidio and Renfro. See Figure 1. Third, we provide a narrative-style literature review of existing book publications on precast concrete, particularly

focusing on books that appeal to architects and building designers.



Figure 1: Selected precast projects. From left to right, Perot Museum of Nature and Science, with traditional architectural precast concrete; Museum of Civilizations of Europe and the Mediterranean (MuCEM), with ultra-high performance concrete (UHPC); The Broad, with glass-fiber reinforced concrete. Sources (from left to right): (Cutrer 2017, Harald 2013, Author 2016)

1.0 PRECAST VARIABLES

1.1 Materials

A typical precast concrete mix includes cement, large and small aggregates, water, and relatively small amounts of additives, admixtures, and air. Within a typical architectural precast mix, the designer can specify grey or white Portland cement, specific aggregates to meet performance or aesthetic standards, and additives and admixtures to decrease required water or cement, alter color, or improve durability and performance. Engineers will require that the precast concrete be reinforced; typically, this includes reinforcing steel and welded wire reinforcement (WWR) but can also include prestressing strands—either pre- or post-tensioned. Other specialized concrete mixes include fiber reinforced concrete (FRC), typically with alkali-resistant glass fibers; UHPC, which uses fine aggregates and steel or glass fiber reinforcing; and polymer concrete, which uses thermoset plastic as the binder rather than Portland cement.

Architectural precast can be made into composite panels that may use two different concrete mixes or may have other materials (e.g. brick, ceramic tile) in the finish surface. If the composite has two concrete mixes, often the more expensive white cement-based concrete will be used for the panel's exterior with a less expensive grey cement-based concrete as the backing material. The two concrete wythes may be bonded to one another through chemical and mechanical bonding, or they may be separated by solid insulation that provides a thermal break between the concrete wythes. If the panels have a thin facing brick, then the bricks are set into a form liner that holds the bricks during casting and provides a profiled shape to the concrete between the bricks that mimics tooled mortar.

1.2 Manufacturing processes

Typically, architectural precast is manufactured by placing a wet concrete mixture into a mold and using gravity and vibration so that the concrete fully fills the mold cavity. Other types of precast manufacturing include centrifugal or spin casting, which spins a hollow, cylindrical-shaped mold filled with concrete at high speeds, using centrifugal force to compact the concrete against the mold; and contact molding, which applies layers of FRC against a mold to create a shell-like component. Generally, a given architectural precast producer does not have the capacity to use all three manufacturing processes.

1.3 Shipping and erection

In nearly all cases, practical limitations related to shipping and erection constrain the physical sizes and maximum weights of precast concrete elements, especially if elements must be transported by truck. Exact limits on size and weight for shipping vary by locality, route, available equipment, and jobsite. Elements measuring up to 12 ft by 40 ft and weighing 20 tons or more are relatively common, with larger and heavier elements possible. Smaller elements can be common, particularly on jobsites that are congested or must be serviced with lower capacity handling equipment such as tower cranes. During the initial phases of architectural design, the precaster, engineer, and contractor can help optimize designs for shipping and installation.

1.4 Mold materials

Architectural precast molds can be made of a range of materials, each affecting its cost, durability, life span, tolerances, panel design, desired finish, and fabrication methods. Generally, as a mold material's cost increases so does its durability and its life span. Architectural precast may be formed on foam, thermoplastic, wood (including plywood, medium-density fiberboard (MDF), etc.), glass fiber reinforced plastic (GFRP), cast elastomeric or rubber, carbon fiber reinforced plastic (CFRP), aluminum, or steel. Foam is the least durable mold material and lasts for only 1-3 castings, or pulls, while steel is the most durable, lasting for 200 pulls or more. Plastic and wood molds tend to warp over multiple castings due to the concrete's moisture and heat of hydration, and they are dimensionally

unstable with long-term temperature and humidity changes, thus impacting how long the mold can be stored. The panel design is impacted by the mold material. For example, foam requires large draft angles to demold the concrete without damaging the foam surface, while rubber is flexible and can accommodate steep or even negative drafts. If the precast is left as-cast, meaning no post-production finishing is done, then the mold material impacts the concrete's surface. Wood can leave its grain on the concrete surface, while epoxy-coated wood and foam leave a matt finish. Rubber can leave an egg-shell finish on the concrete surface, while polished steel and gel-coated GFRP molds can leave a satin or semi-gloss finish on the concrete surface. Some mold materials like foam can be fabricated by CNC equipment; while thermoformed plastic, GFRP, and rubber are a two-step process that requires the mold to be formed on a master mold.

1.5 Mold configurations

Typical architectural precast molds are open, horizontally oriented, and the precast's best face is cast finish-side-down against the mold. Alternatively, molds can be semi-closed or closed with only a small opening to pour the concrete. Closed precast molds may be cast in horizontal, vertical, or inclined orientations, and the orientation will affect the component's finished surface. For wet casting, molds need to be caulked at all joints to keep the cement paste out of the joint, which damages the mold or casting when demolding. Precast molds are either envelope molds, which are five-sided molds in which the mold sides are left intact during demolding, or they are built-up molds, in which one or more mold sides are removed for demolding. Built-up molds require caulking at the mold edges, thus increasing mold set-up times; however, envelope molds require draft angles at the edges and cause additional wear on mold surfaces.

Molds can represent a large cost in the production of architectural precast (*Architectural Precast Concrete*, 2007). To reduce costs, producers want to reuse molds as many times as possible so that mold costs are amortized over the number of units produced. Often this is at odds with an architects' desire to minimize repeated elements. Architectural precast molds are sophisticatedly configured to address this balance. Molds may have tessellated or modular components, or be made with elements, inserts, or plugs that can be moved, eliminated, or flipped between pours to create individual panel designs. Examples include the rubber modular mold components for the Perot Museum that were reorganized and the window forms for One South First's window forms that were rearranged and flipped 180° between castings. For some projects, such as the MuCEM, the screen UHPC panels were cast vertically in closed, two-sided mold that allowed the panels to be placed on the building in four different orientations—original, turned upside down, flipped backwards, or flipped backwards and turned upside down. See Figure 2.

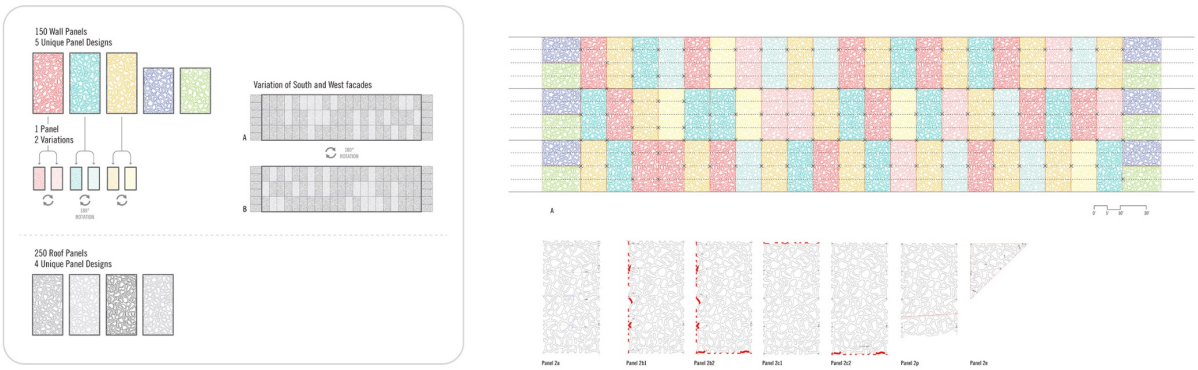


Figure 2: How the two-sided, UHPC screen panels are distributed, flipped, and rotated on the MuCEM. Source: (Lawing and Layman 2020)

1.6 CNC equipment

Precasters use CNC equipment to fabricate architectural precast molds. Directly, CNC millers and hot wire foam cutters can fabricate foam molds. Collaborative research between Oak Ridge National Laboratories (ORNL) and PCI investigated using the potential to use large-scaled 3D printing to fabricate molds. For One South First, Gate Precast used 3D printed CFRP molds; after printing, the molds were milled smooth by a five-axis CNC-miller, and the concrete was cast directly on the molds' surface to form window openings. Indirectly, CNC equipment may fabricate master molds from foam, MDF, or plaster and then the masters are used to fabricate precast molds from contact-molded GFRP, thermoformed plastic, or cast rubber.

2.0 CASE STUDIES

2.1. Overview

Through on-going research, we have gathered over 175 examples of notable custom architectural precast projects that have been completed in the last twenty years (2004-2024). See Table 1. We have identified our case studies through architectural print magazines (e.g. *Architect*, *Architectural Record*), architecture books (e.g. *Detail in Contemporary Concrete Architecture*, *Modern Concrete Construction Manual*), architecture and design-based websites (e.g. *ArchDaily*, *Dezeen*), industry organization design awards (e.g. PCI Design Awards), producer websites (e.g. Gate Precast, Lafarge), and architecture firm websites. To qualify, the building must be notable in its

design, have custom architectural precast elements, and its custom molds must have been used for more than one casting.[1]

Table 1 is an excerpted list of our collected case studies, organized in alphabetical order by architecture firm and includes any known, notable precast variables, such as concrete mix design, manufacturing processes, and mold configurations.

Table 1: Case study list of architectural precast examples. Source: (Authors 2024)

Architect Firm	Building Name	Year	Notable Precast Variables
ACME	*Sächsische AufbauBank (SAB)*	2021	Centrifugal Casting. Steel mold.
ACME	*Victoria Gate Arcades*	2016	Concrete and brick composite panel
Adjaye Associates	*Sugar Hill Development Broadway Housing Communities*	2014	Rubber, photo engrained form liner. Window molds moved between casting to increase panel variety.
ALA Architects	*Kuopio City Theater*	2014	GFRC. Spray applied.
Alloy LLC	*Dumbo Townhouses*	2015	UHPC
AND	*Melting House*	2022	UHPC
Antistatics Architecture	*Wenzhou Ou-river Cystal Boxes Restaurant*	2020	UHPC. Cast in closed, rubber mold.
Architecture Studio	*Al Nahr*	2021	UHPC
AREP	*Lorient-Bretagne Sud Railway Station*	2017	UHPC
Arquitectura Nacional	*Casa Ventura*	2020	GFRC. Spray applied.
AUM architecture	*Cepovett Headquarters*	2018	UHPC
AUM architecture	*House under the Cliff*	2019	UHPC
Baier Bischofberger Architects	*Galerie Bruno Bischofberger: Pappardellehalle*	2013	Stainless steel reinforcing steel used when concrete coverage was not adequate to protect from corrosion. Closed, steel mold.
Baier Bischofberger Architects	*Galerie Bruno Bischofberger: Wellenhalle*	2013	Steel mold.
Belzberg Architects Group	*Apertures*	2022	Polymer-based concrete. Cast in a closed, steel mold.
BLACKhome	*YUE Art Gallery*	2018	UHPC
BNIM	*Tenth and Wyandotte Parking Garage*	2015	Steel mold with two-part rubber inserts. Inserts would be rearranged between pours to increase panel variety.
C.F. Moller Architects	*Danish Meat Research Institute*	2014	Concrete and brick composite panel
C.F. Moller Architects	*Technical Faculty University Southern Denmark*	2015	UHPC
Claudio Vilarinho	*Institute of Science and Innovation for Bio-Sustainability*	2015	GFRC. Spray applied.
COOKFOX Architects	*One South First*	2018	3D-printed, CFRP molds and built-up plywood molds to form window profiles. Window molds moved and flipped between casting to increase panel variety.
Dick van Gameren Architecten	*Block A Noordstrook*	2009	Concrete and brick composite panel
Diller Scofidio + Renfro	*The Broad*	2015	GFRC. Spray applied. Three different molds used (foam, gel-coated foam, GFRC), depending on durability needs.
Durisch + Nolli Architetti	*Federal Criminal Court*	2013	GFRC. Spray applied.
ECDM	*Day Nursery Rue Pierre Budin*	2012	UHPC
Ecker Architeckten	*Forum Eckenberg Academy*	2013	Centrifugal Casting.
Elenberg Fraser	*33 Mackenzie Street*	2013	Cast in a steel mold. Painted for final finish.
EM2N	*Extension Herdern Railway Service Facility*	2013	GFRC. Spray applied.

Empresa de Desarrollo Urbano	*EDU Headquarters*	2017	Wet cast GFRC
Estudio Arqtipo	*GU 2787*	2016	Lightweight concrete mix design
Estudio Arqtipo	*MA 3706*	2016	Lightweight concrete mix design
FCJZ atelier	*Concrete Vessel*	2018	GFRC
Foster + Partners	*Masdar Institute*	2010	GFRC
Franz&Sue	*Collections and Research Center of the Tyrolean State Museum*	2017	GFRC. Spray applied.
Gustau Gili Galfetti	*School Rossend Montane*	2011	Polymer-based concrete
Heatherwick Studio	*Little Island Park*	2021	Foam mold
Hild und K Architekten	*Hotel Werk*	2020	Concrete and brick composite panel.
Hild und K Architekten	*S40 Schwabinger Tor*	2017	Concrete and brick composite panel. Strips of rubber mold formliners to hold bricks and laid on plywood mold.
Hiroshi Nakamura & NAP Co, Ltd.	*Radiator House*	2016	Wet cast GFRC. Cast on rubber mold. Rubber mold cast against CNC-milled plaster master mold. Precaster applied non-stick, fluorocarbon polymer coating to repel water and dirt stains.
Huttunen-Lipasti-Pakkanen Arkkitehdit	*Lansisatamankatu 23*	2014	Wet cast GFRC
ikon.5	*Health and Wellness Center for Suffolk County Community College*	2019	Plywood mold with wood and plastic to form reveals. Mold sides are adjustable to produce different widths for variety.
Inrestudio	Kaleidoscope Office and Residence	2022	GFRC. Spray applied.
Johnston Davidson Architecture	*Lewis Estates Fire Hall*	2015	UHPC
K2S Architects	*Fazer Headquarters*	2016	Polymer-based concrete
Kapadia Associates	*BAPS Swaminarayan Girls Residence School*	2016	GFRC. Spray applied.
Kengo Kuma & Associates	*V+A Dundee*	2018	Steel molds that are angled between pours to create cross-sectional variety. Mold ends are dammed to create different lengths. Concrete retarder used to expose aggregate.
Kevin Daly Architects	*UCLA Ostin Basketball Center*	2017	GFRC. Spray applied.
Key Operation Inc/ Architects	*Kannai Blade Residence*	2021	UHPC
Kirsi Korhonen and Mika Penttinen Architects	*Lontoonkatu 9*	2013	GFRC. Spray applied.
KSP Jergen Engle Architeken	*Great Mosque*	2017	Centrifugal Cast with custom rubber formliner for decorative base.
Lake | Flato	*Confluence Park Pavillion*	2018	GFRP molds.
LMN Architects	*Global Center for Health Innovation*	2013	Foam master mold, dammed to form different rubber molds. Rubber molds ganged for larger panels.
Louis Paillard Architecte & Urbaniste	*229 Logements*	2017	Rubber molds.
Maki and Associates	*Aga Kahn Centre*	2018	UHPC
Manuelle Gautrand Architecture	*Lille Modern Art Museum*	2010	UHPC
Marc Mimram	*Gare TGV*	2017	UHPC
mecanoo	*Palace of Justice*	2017	GFRC. Spray applied.
Morphosis	*Perot Museum of Nature and Science*	2012	Rubber mold modules that can be rearranged to increase panel variety.
NBBJ Architects	*James F Battin Courthouse*	2012	Rubber molds.
NBBJ Architects	*Leonard J. Samia Academic Center*	2015	Wood molds.
Nemesi	*2015 Milan Exposition Italy Pavilion*	2015	Polystyrene molds.

Neri & Hu	*Aranya Art Center*	2019	GFRC.
Niall McLaughlin Architects	*Stratford Athletes' Village*	2012	Rubber molds with undercuts. Wood dams used to form smaller panels.
Nieto Sobejano Arquitectos	*Contemporary Art Center*	2013	GFRC with integrated foam core.
NOAHH	*Amare Home of the Performance Arts*	2021	Steel closed molds. Elements cast on incline angle to reduce bug holes.
OMA	*Lab City CentraleSupelec*	2017	Integrated color pigment.
Perkins+Will	*Florida International University Science Classroom Complex*	2013	Wood mold.
PROMONTORIO	*Embassy of Egypt*	2017	GFRC. Spray applied. Rubber mold.
ra15 a.s.	*Hotel Urban Crême Prague*	2019	GFRC. Spray applied.
Rafael Vinoly Architects	*277 Fifth Avenue*	2019	Integrated custom color pigment
Rivka Night	*The Gold Line Bridge*	2012	Composite concrete panel.
RKW Architektur	*Motel One*	2014	GFRC. Spray applied.
Rogers Partners	*Henderson-Hopkins Elementary School*	c.2015	Integrated color pigment
Rudy Ricciotti Architecte	*MuCEM*	2013	UHPC. Cast in closed, vertical mold.
Rudy Ricciotti Architecte	*Pavilion 52*	2018	UHPC
Rural Urban Framework	*Angdong Hospital Project*	2011	Rubber molds
SHoP Architects	*290 Mulberry Street*	2013	Concrete and brick composite panel. Rubber mold cast against CNC-milled master mold. Master mold dammed to create rubber mold varieties.
Silvio d'Ascia Architecture	*Kenitra Train Station*	2019	UHPC
SOM	*Chhatrapati Shivaji International Airport Terminal 2*	2014	GFRC. Spray applied.
Spridd	*Weave*	2018	
SR Arquitectos	*Alqueria Gourmet Market*	2019	Polymer-based concrete
studio kimiis	*Concord Park Pavilion & Trellis*	2019	UHPC
TF International	*Chinese Cultural Center of Belgrade*	2020	UHPC
THE_SYSTEM LAB	*Hannam-Dong HANDS Corporation Headquarters*	2014	Steel molds.
Thomas Phifer and Partners	*Glenstone Museum*	2018	Plywood molds.
Touzet Studio	*Nike Miami*	2017	UHPC
University of Southern California School of Architecture	*Carapace Pavilion*	2022	UHPC. Cast in closed mold. Upper mold half made from bent plywood. Lower mold half made from CNC-milled foam with GFRP outer layer. Mold was dammed and plugs for apertures were removed as needed to increase panel variety.
Urbanus	*Shum Yip UpperHills Loft*	2018	UHPC
Willmotte & Associes	*Le Verone*	2021	UHPC
WORK Architecture Company	*Kew Gardens Hills Library*	2017	GFRC with integrated color. Spray applied.
Zaha Hadid Architects	*One Thousand Museum Tower*	2019	GFRC. Spray applied.

3.0 AVAILABLE BOOK LITERATURE

Most of the books on precast concrete focus on structural precast and are good resources for civil and structural engineers; books include *Novel Precast Concrete Structural Systems* by Gang Wu et al., *PCI Design Handbook* by

PCI, and *Precast Concrete Structures* by Hubert Bachmann and Alfred Steinle. For this paper, we provide a narrative-style literature review of books that architects would use to learn about the possibilities of designing with architectural precast. Books are listed as they would appear in a bibliography.

3.1 *Architectural Precast Concrete*. 3rd ed. Chicago, IL: Precast/ Prestressed Concrete Institute, 2007.

This book is written by the PCI Architectural Precast Concrete Committee. PCI is the "technical institute and trade association for the precast, prestress concrete structures industry" in the United States (PCI, 2024). This book communicates what the industry would like architects to know about architectural precast concrete. The book covers an overview of architectural precast; design concepts related to use and economics; surface aesthetics that include mix design, design parameters, postproduction finishing, and weathering; structural design; construction documents and specification language; sustainability issues such as life-cycle analysis and building rating systems; and performance metrics such as thermal and blast resistances and acoustics. It does include basic design parameters based on the precast mold. This book does not include exemplary architectural projects, nor does it include the latest innovations regarding mold fabrication technologies (e.g. CNC equipment), mold configuration techniques (e.g. tessellated patterns), or closed vertical molds. Also, it does not include information about UHPC, FRC, or polymer concrete.

3.2 Bennett, David. *The Art of Precast Concrete: Colour Texture Expression*. Basel: Birkhäuser, 2005.

This book uses built case studies to provide information on architectural precast. The beginning gives an overview of architectural precast in northern Europe, including economics of use, manufacturing culture, and alternative precast mix designs (e.g. UHPC, GFRC). Each case study includes text, written by the architecture firm, about the project's architectural statement, and text by the project's precaster. The case studies include architectural drawings (e.g. plans, sections, and elevations); photographs of the completed building, precast elements, and details; and for most projects there are photographs of the precast's manufacturing and installation. The focus of the book appears to be on the case studies' mix design and post-production finishing. Most of the book's case studies use simple molds to form flat panels, with only a few that have highly articulated surfaces afforded by CNC equipment.

3.3 Cohen, Jean Louis and G. Martin Moeller, Jr., Ed. *Liquid Stone: New Architecture in Concrete*. New York: Princeton Architectural Press, 2006.

This book is the result of a 2004-2006 exhibition by the same name, presented at the National Building Museum in Washington, DC. The book begins with individual author-contributed architectural essays on concrete that position the material relative to architectural historic and theoretic frameworks. The remaining five-sixths of the book are dedicated to architectural examples of projects that celebrate concrete, curated around particular themes. The book refers to technical aspects of concrete only when necessary and presents technical details for only some of the projects. Most of the examples are of site-cast concrete, with only two being of precast concrete. Although the curated projects are compelling there is little technical information presented in this book that helps advance our understanding of the architectural implications of concrete.

3.4 Levitt, Maurice. *Precast Concrete: Materials, Manufacturing, Properties and Usage*. 2nd ed. London: Taylor & Francis, 2008.

This book is a good introductory resource for beginning civil and industrial engineers that will either work with precast concrete or in the precast concrete industry. Topics include in-depth information on ingredients, reinforcing and prestressing steel, hardware, molds, production control, manufacturing processes, curing, performance, quality control and quality assurance, and finishing. The chapter on molds focuses on the reusability and longevity of different molds, while secondarily discussing the mold material's impact on the precast surface. Like *Architectural Precast Concrete*, this book does not discuss mold innovations. There is limited information on fiber reinforced concrete and no information on UHPC or polymer concrete.

3.5 Peck, Martin and Christina McKenna ed. *Modern Concrete Construction Manual: Structural Design Material Properties, Sustainability.* Munich: Institute für Internationale Architektur-Dokumentation, 2014.

Part of a series published by *Detail*, the first two-thirds of this book provides an overview of concrete, design consideration criteria, CAD/ CAM fabrication methods, and performance metrics. The book distinguishes between site cast and precast concrete and discusses the benefits and differences of each. The last third of the book includes nineteen examples of completed buildings with short project statements, photographs of the completed project, and often architectural drawings (e.g. plans, sections), section and plan details, and construction and fabrication photographs. Although many of the examples are of precast concrete, most examples have flat panels with little articulation or innovation in manufacturing methods.

3.6 Phillips, David and Megumi Yamashita. *Detail in Contemporary Concrete Architecture*. London: Laurence King Publishing, 2017.

Part of a series published by Laurence King, this book presents contemporary case studies of buildings that make notable architectural use of concrete and includes both site and pre-cast casting methods. Organized by building type, each case study includes photographs of the completed building, architectural drawings (e.g. plans, sections), and technical details. Each case study includes the building title, location, client, architecture design team, structural engineer, and contractor, as well as a brief project overview. The book includes a CD of the book's vector files in .dwg format. The book makes little distinction of different concrete mixes, their properties, and casting methods.

CONCLUSION

CAD/CAM has allowed for the design and fabrication of custom components with geometric complexity and the architectural precast concrete industry has responded by developing techniques to produce panel variety while balancing the need to reuse molds. This paper presented typical precast variables that designers need to consider when working with architectural precast, a list of exemplary projects with notable architectural precast elements, and a narrative-style literature review of current book publications.

Our literature review focused on books that would appeal to architects and designers. In our review, some books provided inspiring examples and technical information about precast but included it with site-cast concrete as if the two materials are similar. We would argue that although both site-cast and precast concrete generally use the same raw materials, the variables associated with precast make it distinct from site-cast concrete. Some books were dedicated to precast concrete; however, those books do not include exemplary architectural projects or innovations in mold-making techniques. The current books on precast would not inspire architects and designers to consider architectural precast in their designs or push precasters to explore new manufacturing techniques. Our future goal of this research is to propose creating a guide for architects that demonstrates what is possible when designing with architectural precast.

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ENDNOTES

[1] We have chosen not to include architectural projects that rely heavily or fully on single use-molds. An example is Zaha Hadid’s Heydar Aliyev Center, which uses single use plywood molds for each of its GFRC panels (Winterstetter, 2015).

Robotic Concrete 3D Printing Continuous Toolpath Planning: From Single Curve to Voxel-Based Systems for Design-to-Production of Urban Furnitures

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ABSTRACT: This paper discusses the development of integrated design-to-production frameworks for Robotic Concrete 3D Printing (RC3DP) of context-specific urban furniture projects. The study focuses on two main objectives: developing computational methods for continuous toolpath planning of bespoke components and examining integrated frameworks to make design-to-production systems more socio-environmentally inclusive and tailored to specific contexts. Following an introduction to outline the key challenges of continuous robotic concrete 3D printing, the paper is organized into two sets of case studies. The first set explores curved-based continuous 3D printing for surface-based design strategies, and the second set investigates voxel-based approaches for volumetric design 3D printing. Curve-based projects consisted of three case studies. The first case uses an AI-enabled generative system to translate a porous, cellular structure to a continuous toolpath with variable heights. The second case study is based on a workflow using a controlled reaction-diffusion algorithm as a generative strategy to create continuous infill for complex geometries. The third project focuses on growing larger than the size of the production setup by testing the assembly of multiple printed components, all produced with continuous toolpaths. The workflows and projects are developed as an integral part of a graduate-level digital design and fabrication course focusing on inclusive automation and robotic concrete 3D printing. Therefore, in addition to sharing the details of the developed computational design to production methodologies, the paper discusses the research findings from pedagogical lenses. Building on these cases, the investigation advances to the development of a generative system centered on voxels, employing a tetrahedron structure. This volumetric approach simultaneously produces external surface tectonics and internal infill through a seamless toolpath. The paper concludes by presenting sets of guidelines and future directions for both the introduced curve and voxel-based approaches in Robotic Concrete 3D printing, emphasizing the early integration of computational and fabrication intelligence into the design process.

KEYWORDS: Continuous toolpath planning, robotic concrete 3D trinting, voxel based 3D printing, urban manufacturing, integrated design-to-production

INTRODUCTION AND BACKGROUND

Recent research in 3D concrete printing technology has shown significant potential to revolutionize the construction industry by enabling the fabrication of complex building and structural elements such as columns and bridges (Anton et al. 2021; Ahmed et al.). Several physical factors, such as fluidity, print speed, material aggregates, temperature, and admixture, all influence the printing quality (Lyu et al. 2021). Moreover, having a successful print heavily depends on toolpath planning since on-and-off printing with a liquid material like fluid concrete is nearly impractical with commonly available technologies. Therefore, it is crucial to develop customized workflows for toolpath planning during the initial design phase when printing non-standard and context-specific designs.

In the realm of digital prototyping for additive manufacturing, this paper presents recent advancements in toolpath-based design methodologies, particularly tailored for applications in Fused Deposition Modelling (FDM). FDM is characterized by the layer-by-layer linear deposition of molten material. The methodologies developed in this study harness advanced techniques, including topology optimization, principal stressed lines, and bio-inspired generative patterns, to inform toolpath design and planning (Breseghello and Naboni 2022; Mostafavi et al. 2015; Mehan and Mostafavi 2022). Moreover, these approaches align with contemporary principles outlined in earlier research efforts focusing on data-driven 3D printing strategies (Bao and Yan 2023; Bao et al. 2020, Lu et al. 2023). These studies delve into domains such as data-driven, performance-based generative design, digital fabrication, and bioinspired architectural design, considering environmental and structural criteria (Mehan and Mostafavi 2024a; Azulay et al. 2023; Feng 2022; Li et al. 2023). Expanding on recent advancements in evolutionary topology optimization of continuum structures, as explored (Mehan and Mostafavi 2024b; Huang and Xie 2010), these insights serve as a foundational basis for advancing toolpath-based design methodologies within the context of additive manufacturing and digital prototyping for creating architectural material systems (Bouaziz 2008)

This paper will present three urban furniture projects built on a one-to-one scale, each addressing specific challenges related to continuous toolpath planning. The first case uses an AI-enabled generative system to translate a porous cellular structure to a continuous toolpath with variable heights (Mostafavi et al. 2024). The second case study is based on a workflow using a controlled reaction-diffusion algorithm as a generative strategy to create continuous infill for complex geometries. The third project focuses on growing larger than the size of the production setup by testing the assembly of multiple printed components, all produced with continuous toolpaths. The workflows and projects are developed as an integral part of a digital design and fabrication graduate-level course focusing on inclusive automation and robotic concrete 3D printing. Therefore, in addition to sharing the details of the developed computational design to production methodologies, the paper discusses the research findings from pedagogical lenses (Mehan 2024; Mehan and Stuckemeyer 2023).

Expanding upon these three cases, the study progresses to the creation of a generative system based on voxels, utilizing a tetrahedron structure. This framework generates both the external surface tectonics and internal infill through a seamless toolpath. The purpose of this system is to overcome the challenges stemming from the lack of curvature in Concrete 3D Printing, thereby minimizing stress concentration on flat surfaces. To achieve this, the workflow incorporates a recursive subdivision technique in regions prone to tension accumulation, consequently reducing the risk of buckling during and after the printing procedure.

The resultant design materialization system is adaptable to various boundary representation forms as input. Through the voxelization algorithm, the input geometry is transformed into voxels, eliminating unnecessary inner fill while preserving essential voxel elements. Following this, two strategies for generating continuous toolpaths are formulated and assessed: the single-layer approach and the double-layer approach. Both strategies ensure the uninterrupted trajectory of the printing process.

1.0 CURVE BASED CONTINUOUS 3D PRINTING

The upcoming section introduces three continuous toolpath generation followed by case studies, each exploring the context and design objectives of forthcoming projects, the usage of generative AI, designer-based forms and computationally applied patterns into a predesigned form. Employing Rhinoceros and Grasshopper 3D as CAD/CAM interfaces, the toolpath for concrete 3D printing utilizes the customized HAL robotics system for XtreeE's large-scale 3D printing extruder mounted on a KR210 KUKA robotic arm. The discussion further examines the approaches taken for continuous toolpath planning in each project to enable the application of required transformation of the initial concept design into design to production enabled workflow (Mehan et al., 2023). Each case description concludes by emphasizing key features and findings derived from the one-to-one prototyping and assembly phases of concrete components and structures.

1.1 AI-Generated printable porosity

The initial case employs Artificial Intelligence (AI)—to enable the generative system to transform a porous, cellular structure in the format of 2D images into a continuous 3D toolpath with variable heights. The design goal is to create a structure with openings that smoothly incorporate seating elements into the wall, each characterized by a distinct pattern and degrees of porosity. The goal is to enhance the overall quality of outdoor space by improving the entry of natural light and offering effective wind protection by creating seating areas with perforated walls between existing columns of the promenade. The design processes apply generative AI to produce a series of images with porous patterns, utilizing the Midjourney platform with targeted prompts such as "porosity," "canopy," "biomechanic," "bench," "wall," and "organic" as the foundation for subsequent stages.



Figure 1: AI-Generated Printable Porosity: Left - Macro-scale cellular structure generated with AI; Middle - Continuous printing at varied heights; Right - Simulation diagram of the print. Source: (First and second Authors, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Abel Gonzalez, Edgar Montejano, Cristian Solis, Matthew Stevens, Benjamin Varner)

The next step in the process involves the images serving as input to a subsystem that applies a developed algorithm utilizing the Image Sampler. This algorithm translates the pixelated 2D result into a continuous 3D toolpath by reading the binary values of each voxel. Discretization techniques based on penalization algorithms, such as

Voronoi or hexagonal patterns, are then employed to create a cellular structure representing the generated porosity. A toolpath is generated, connecting the cellular structure in the subsequent phase. Following the generation of the continuous toolpath, the prototype undergoes concrete 3D printing, utilizing the defined toolpath for material deposition and materialization of the design (Figure 1).

By generatively creating sets of porous images and algorithmically translating the results into a printable continuous toolpath, the design-to-production system allows for iterative exploration of different structures with varying porosity levels. The density and quantity of polygons are transformed into an assembly of shapes arranged into a cohesive structure with varying depths, creating a gradient of solid and void areas. This form, applied to a walled screen with a bench, manifests inherent patterns in a structured manner, reflecting the algorithmically designed solar analysis and daylight gain. The shading wall serves as a criterion for choosing the desired porosity level, generated through AI and controlled with sets of parameters in the algorithm that translate the image to a robotic concrete 3D printing toolpath. Figure 2 illustrates the one-to-one prototype printed in three different heights in one continuous toolpath following the algorithmically generated curve.

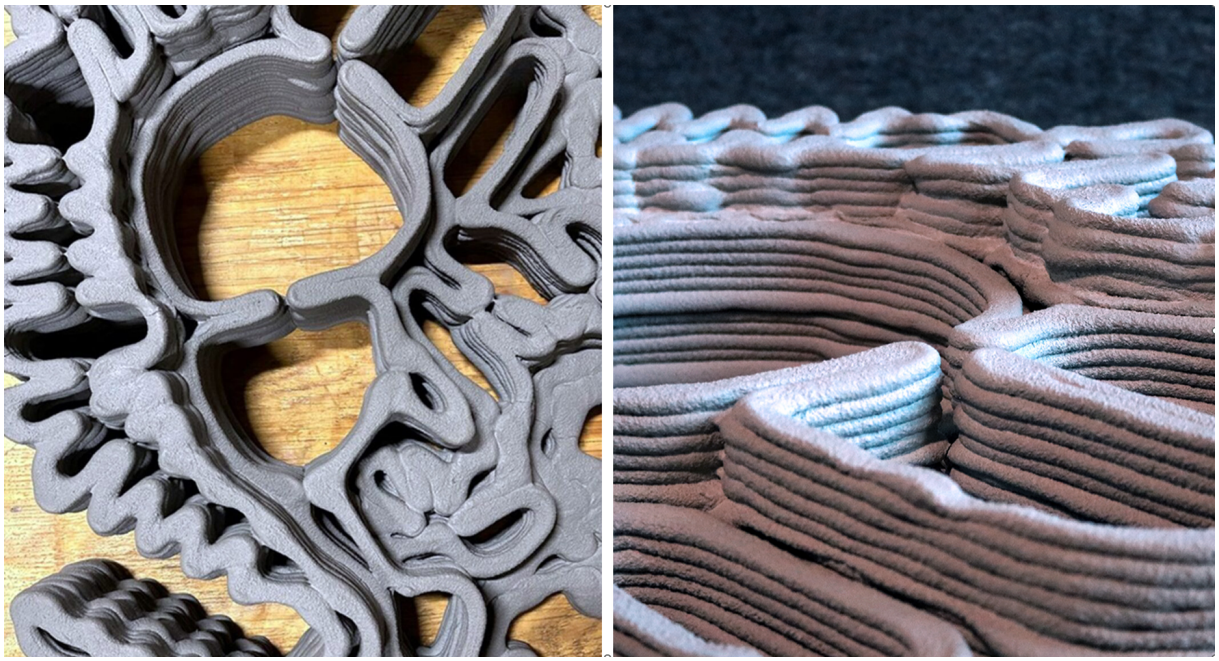


Figure 2: AI-Generated Printable Porosity: Left - Top view; Right - Side view with varied heights in three layers, produced with a continuous toolpath. Source: (First and second Authors, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Abel Gonzalez, Edgar Montejano, Cristian Solis, Matthew Stevens, Benjamin Varner)

1.2. Concreted 3D printed stacked wall

The Concrete 3D Printed Stacked Wall project introduces a system where multiple components stack, creating a Tetris-like structure. This endeavor addresses challenges in 3D printing structures, particularly in assembly processes. The inherent challenge in 3D printing structures lies in assembly and producing components rather than continuous walls and shells. The initial concept involved the consideration of constructing a wooden shelter or causeway, drawing inspiration for the project from the specific urban context adjacent to an archaeological site. Additionally, the project explored integrating sets of niches—recesses with varying sizes and depths designed for displaying objects found in the archaeological site. The research aims to integrate the wooden shelter with traditional inset walls in adobe houses, examining ways to combine walls with shading. Within this context, the structure aims to create a wall using customized components, each featuring niches or cavities to showcase historical objects in the archaeological site. The wall consists of concrete-printed stacked components with a wooden shading structure above it.

The toolpath design strategy employed in this project centers on creating a continuous cavity within each component for concrete casting, followed by developing a continuous printing path for the outer boundary of the components connected to internal niches. Consequently, each stacked component comprises an extruded curve featuring internal niches with slightly tapered angles towards the front side of the wall. The outer surfaces are intentionally flat, contributing to a Tetris-like interlocking configuration for assembly. Despite the fragility of the straight, non-curvilinear outer boundaries, the internal cavities connected to the outer boundary significantly enhance the overall stiffness of each component. Figure 3 provides an overview of the design in a sectional model, illustrating the printing process of components with varying sizes and typologies.

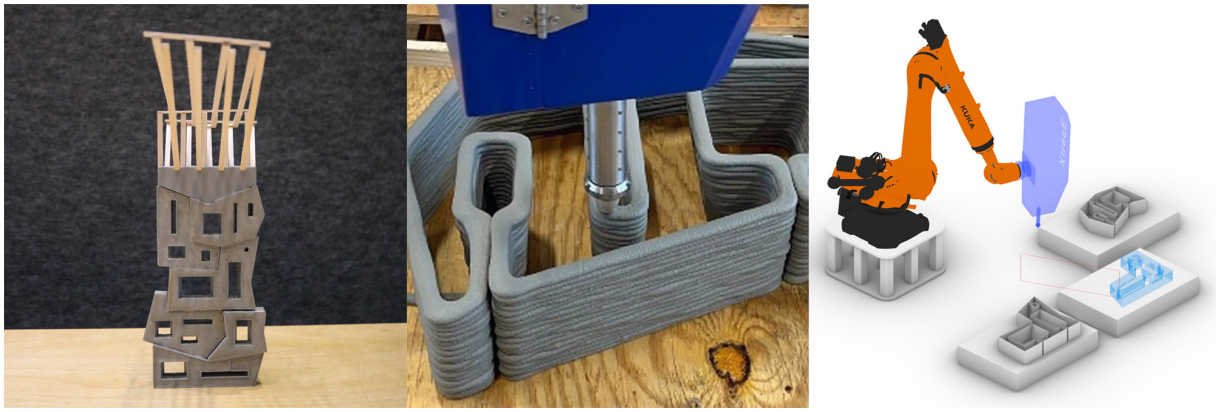


Figure 3: Concrete 3D Printed Stacked Wall: Left - Sectional model showcasing integrated niches and enclosed cases within the printed components; Middle - Continuous 3D printing process; Right - Simulation diagram of the print. Source: (First Author, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Elias Hernandez, Alexis Hunsucker, Zahra Khodabakhsh, Maria Guadalupe Martinez, Derek Williams)

The one-to-one prototype of the stacked wall presented in this paper comprises three components with L and V typologies, systematically stacked on top of each other. Figure 4 represents the assembled wall within the internal cavities before the concrete casting process. A notable aspect of the developed material system involves integrating high-performance printable concrete materials with more readily available conventional concrete. The use of concrete glue acts as an adhesive to bind the elements together, and careful consideration is given to the weight distribution in each component and the positioning of the center of gravity post-assembly, addressing an essential criterion in the design development.



Figure 4: Left: A one-to-one prototype of the Concrete 3D-Printed Stacked Wall featuring three L- and V-shaped components; Right: a close-up view of the tapered niches. Source: (First Author, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Elias Hernandez, Alexis Hunsucker, Zahra Khodabakhsh, Maria Guadalupe Martinez, Derek Williams)

1.3. RC3DP reaction-diffusion bench

The RC3DP Reaction-Diffusion Bench project focuses on integrating bio-inspired generative patterns into the continuous 3D printing process, aiming to enhance the stiffness and stability of printing surfaces during fabrication and post-production stages. In this case study, the reaction-diffusion model functions as a mathematical framework, elucidating the processes governing the interaction of materials or chemicals as they diffuse through a shared medium. This system's deliberate selection is driven by the intent to generate internal and external performative tectonics, reinforcing the structural robustness of the printed surface. Additionally, the internal porosity of the bench is designed to harmonize with nature, as the bench is tailored for site-specific community gardens. The porosity within the physical seating contributes to the overall aesthetics and fosters the growth of plants with healing properties, integrated into the built environment.

The developed toolpath planning system takes either single or double curvature surfaces as input, determining the depths of reaction-diffusion based on the reaction time. Increased reaction time results in greater penetration of the diffusion pattern into the internal area. Additionally, informed by previous cases, a preference for double curvature surfaces is observed over the single curvature starting extrusion. This preference leads to improved structural stability at both the micro and macro scales of the entire prototyped bench. The selection of surface geometry and its curvature represents progress in fortifying the structural rigidity of the bench, impacting both micro-surface scales and the overall macro-scale stability. Figure 5 depicts a series of iterations utilizing the generative system, along with printing and corresponding simulation diagrams, showcasing the production process of the prototyped bench.

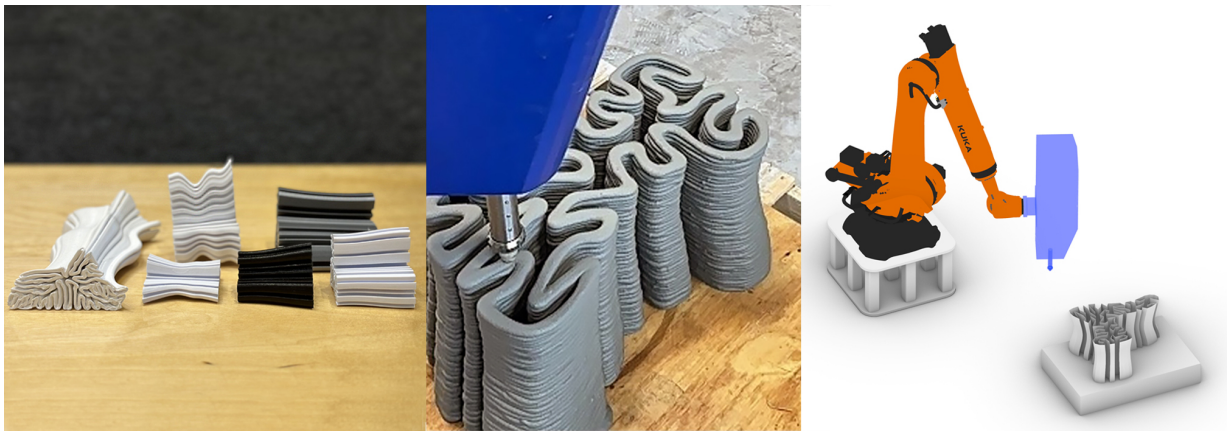


Figure 5: RC3DP Reaction-Diffusion Bench: Left, a sequence of design iterations displayed as scaled models; Middle, the 3D printing process; Right, a simulation diagram of the print. Source: (First Author, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Luke Conrad, Saul Ortega, Judith Peralta Velazquez, Amanda Rich, Georgia Thomas)

The one-to-one prototype bench is contained within a 40x40x80 cm bounding box, incorporating both seating and leaning areas, printed in a single continuous course. The utilization of fractal tectonics and the double-curve surface properties of the bench minimizes material consumption in each layer. Consequently, the material flow has been optimized, enhancing efficiency in material utilization, and strengthening the overall structure of the bench.



Figure 6: Left: One-to-one prototype of RC3DP Reaction-Diffusion Bench, Close-up of the continuous printed pattern. Source: (First Author, 2022. Design, methods, and research developed as part of ARCH 5354 at TTU, led by S. Mostafavi. Team: Luke Conrad, Saul Ortega, Judith Peralta Velazquez, Amanda Rich, Georgia Thomas)

2.0 VOXEL BASED VOLUMETRIC CONCRETED 3D PRINTING

The paper's second set of case studies investigates a volumetric approach to toolpath planning involving the utilization of voxelization to translate voxelated geometries into a continuous toolpath. Subsequent sections will delve into the computational aspects, focusing on the voxelization process and the robotic production of tetrahedra-based pedestals. The study encompasses both single and double layers, aligning with voxel topologies.

2.1. Design computation: voxelization

The computational design system for voxel-based robotic toolpath planning is implemented as an integrated approach, accepting any closed Boundary Representation (B-Rep) volumes as input. The generative method employed in this system applies a voxelization routine, with a specific choice of using a Tetrahedral-Octahedral honeycomb space-filling tessellation. This selection is driven by the method's rectangular-based geometry in horizontal sections and triangular-based topologies in vertical sections. The chosen tessellation guarantees both printability and stability throughout the production process, as the angles consistently remain above 45 degrees during the print.

Figure 7 presents the developed generative system, incorporating recursive voxelization for added stability in critical areas prone to failure during and after the printing process. Recursive voxelization achieves this by subdividing each voxel into smaller units. Subsequently, the toolpath can either consist of a continuous single layer, delineating the volume's boundary, or a double-layer continuous toolpath that follows the internal surface of outer voxels, as depicted in the right portion of Figure 7. This approach reinforces specific regions that are subject to buckling, contributing to enhanced stability and structural integrity.

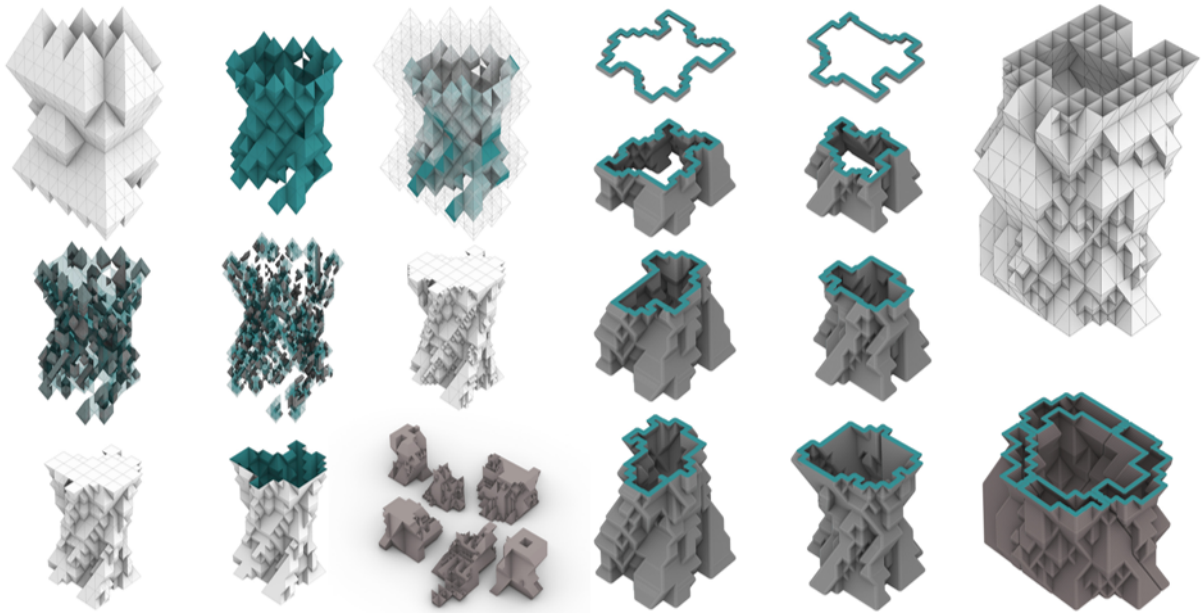


Figure 7: Overview of the computational design workflow translating voxels to surface and toolpath from a closed B-Rep volume. Columns one to three detail the step-by-step process, while columns four and five show the single-layer 3D printing strategy. The last column exemplifies the developed double-layer approach in voxel-based 3D printing. Source: (Authors, 2023. Design and research developed as part of the Design Computation (DCF) ARCH 5604 studio and Smart Materials ARCH 5303 course, led by S. Mostafavi, and the Urban Community Design (UCD) ARCH 5604 course, led by A. Mehan, at TTU in Spring 2023. Methods were further advanced and consolidated by author Ali Etamadi.)

2.1. Robotic production: single to double layer tetrahedral based pedestals

The one-to-one produced set of prototypes for the developed voxel-based toolpath planning, as presented in this paper, consists of four pedestals, each with distinct initial volumes serving as design inputs. The left portion of Figure 8 showcases the four robotically concrete 3D-printed prototypes, providing a visual scale comparison to human dimensions. On the right side of Figure 8, a finite element method analysis delineates areas prone to failure during the print. This analysis guides the application of an additional level of recursive voxelization to strengthen printability throughout the production process (Mostafavi and Mehan 2024). Alternatively, designers may opt for a double-layer voxel-based toolpath planning, as illustrated in Figure 7 and explained in the preceding section (Mehan and Mostafavi 2023). This strategic choice contributes to the overall stability and structural integrity of the printed prototypes.



Figure 8: Left: Prototypes showcasing the voxel-based continuous robotic concrete 3D printing approach; right Finite Element Method analysis of the surface, guiding recursive voxelization for additional reinforcement where needed. Source: (Left: Authors, 2023–24. Design and research developed as part of the Design Computation (DCF) ARCH 5604 studio and Smart Materials ARCH 5303 course, led by S. Mostafavi, and the Urban Community Design (UCD) ARCH 5604 course, led by A. Mehan, at TTU in Spring 2023, exhibited at the ECC Venice Architecture Biennale. Right: Photos taken and produced by XtreeE, an industry collaborator on the project)

CONCLUSION

This paper explores a series of case studies and pilot projects centred on continuous toolpath planning in the realm of Robotic Concrete 3D Printing (RC3DP). The transition from single-curve methodologies to voxel-based systems for designing and producing urban furniture is thoroughly investigated and elucidated. The inquiry initiated with an in-depth analysis and categorization of curved-based continuous 3D printing, showcasing case studies that leverage AI-driven generative systems, controlled reaction-diffusion algorithms, and innovative multi-component assembly strategies – all operating within the cohesive framework of continuous toolpaths. The exploration extends into voxel-based approaches, incorporating a tetrahedral structure to seamlessly integrate external surface tectonics and internal infill.

These projects exemplify the transformative impact of creative toolpath planning, demonstrating adaptability in design for specific contexts and functional requirements. Furthermore, they formulate strategies for implementing performance-driven tectonics that enhance structural stability throughout the printing process and beyond. As future directions for this research, a more comprehensive exploration and application of voxel-based toolpath planning is anticipated. The system holds the promise of delivering a high level of flexibility in design and ensuring structural integrity in the production of building elements and components.

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Hybridity in Architectural Design: Past, Present, and into the Unknown

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ABSTRACT: The aim of this paper is to verify and describe the hybridity between European modern architecture and American traditional architecture in mid-twentieth-century American college towns as expressed in residences built there by faculty members of NAAB-accredited architecture programs. Based on shape grammar as a computational design methodology, a comprehensive analysis is presented to reveal a hybridity phenomenon that though unique has broader implications for our understanding of architectural production.

KEYWORDS: College town modernism, shape grammar, hybridity, faculty-practitioners

INTRODUCTION

In A Field Guide to American Houses, Virginia and Lee McAlester describe “modern” as a post–World War II architecture that abandoned historical precedents in favor of new variations in architectural composition. The modern US houses featured in their book are different—in terms of characteristics—from what we know as European modern architecture as defined earlier in the century by Henry-Russell Hitchcock and Philip Johnson. In Hitchcock and Johnson’s definition, modern architecture—primarily the “International Style”—was understood in reference to three identifying features: volume instead of mass, lack of ornamentation, and regularity and standardization of elements.

The McAlesters’ definition was related to Le Corbusier’s five points for defining the “new” architecture. Rooted in Europe and transferred to and further developed in the United States, modern architecture, was characterized later in the twentieth century by scholars such as Kenneth Frampton, David Handlin, and William Curtis by principles close to those proposed by Hitchcock and Johnson: a tendency to use simple rectangular volume (instead of mass) articulated by regularity, crisply cut openings, flat roofs, the avoidance of architectural decoration, an open floor plan, and a free façade design.

In pursuing the research for the present study, the author documented examples of mid-twentieth-century architecture in college towns across the US and found that many include multiple single-family houses designed by full-time faculty members holding positions with the NAAB-accredited architecture degree programs offered at the colleges located there. Many of these houses constitute a hybridity between European modern architecture and traditional American architecture given that they incorporate many of the shapes, rules, and features of each style. They do not fully fit the existing mainstream of the period. That is, many are not built according to popular mid-century ranch, split-level, shed, or minimal traditional styles. Nor do they feature the characteristics or shapes of modern architecture such as flat roofs, ribbon windows, and free façades, as first identified by Henry Russell Hitchcock and Philip Johnson (1932) and later by scholars such as Kenneth Frampton and William Curtis. Furthermore, these houses are not colonial, revival, or Victorian in appearance and, therefore, do not conform to traditional American styles. Instead, many of the houses simultaneously reflect traditional American styles together with forms associated with modernist ideologies: for example, some houses boast sloped roofs, partially open plans, large windows, a horizontal organization in a split-level arrangement, and traditional balloon frames with local stone, wood, or brick cladding.

While numerous faculty members practiced architecture locally in the mid-twentieth century, based on the preliminary research conducted for the present study, only six of those had both trained according to modern architectural principles in the late 1930s and early 1940s, either directly or indirectly, with one of the European modern architect emigres and practiced during the mid-twentieth century post–WWII period in their respective college towns: Harry Merritt, Edward Olencki, William Hajjar, William Caudill, Leonard Currie, and Charles Burchard. These six architects practiced in only five towns: State College, PA; Ann Arbor, MI; Blacksburg, VA; Gainesville, FL; and College Station, TX (Table 1). It is important to note that all six graduated from one of the “less conventional” architecture programs of the mid-twentieth-century United States, contexts in which students were exposed to modern architectural pedagogy, including Taliesin, Harvard’s Graduate School of Design (GSD), Black Mountain College, the Massachusetts Institute of Technology (MIT), the Georgia Institute of Technology, the Armour Institute (later the Illinois Institute of Technology (IIT)), and the Institute of Design in Chicago (later part of IIT) (Alofsin 2012).

Although these six faculty-practitioners are not nationally known as influential figures in the context of mid-twentieth-century architecture, each had an impact on the architectural taste of local people in terms of their acceptance of modern/hybrid architecture. Therefore, it can be argued that they were, in fact, influential in popularizing modern architecture in the United States during the mid-twentieth century. Pursuit of this argument, however, is outside the scope of this paper and will be explored elsewhere.

The notion of hybridity between modern architecture and traditional architecture, or the duality between modern and traditional, international and local, and designed and vernacular in architectural practice has already been addressed in the literature. Ideas such as “high-style” versus “popular” architecture in the mid-twentieth century, “Brazilian popular modernism,” “critical regionalism,” and “vernacular modernism,” and the contrast between vernacular traditions and the twentieth-century built environment all refer to this duality in various geographic locations and time periods. The central concerns of this paper pertain to whether this hybridity can be verified and described and whether shape grammar—which refers to a specific class of production systems based on an initial shape or set of finite shapes and transformational shape rules—can serve as an effective computational design method for this purpose.

Table 1: Faculty-practitioners in Mid-twentieth Century U.S. College Towns who Graduated from “Less Conventional” Architecture Programs. Source: (Author 2024)

College town	University	Faculty-practitioner	Schools from which they received a degree
Gainesville, FL	University of Florida	Harry Merritt	Harvard
Ann Arbor, MI	University of Michigan	Edward Olencki	IIT
State College, PA	Penn State	A. William Hajjar	MIT
College Station, TX	Texas A&M	William W. Caudill (CRS)	MIT
Blacksburg, VA	Virginia Tech	Leonard Currie Charles Burchard	Harvard MIT and Harvard

In the context of a broader study, the current paper focuses on three college towns that hosted NAAB-accredited architecture programs during the mid-twentieth century: State College, PA, home of Penn State; College Station, TX, home of Texas A&M University; and Ann Arbor, MI, home of the University of Michigan. A systematic methodology is developed for the related purposes of identifying, analyzing, and generating hybridity in architectural design and then used to analyze examples of single-family hybrid houses designed by the faculty practicing architecture in the locales specified.

1.0 THE COLLEGE TOWN: AN AMERICAN PHENOMENON

The idea of university life and of the university community, as Laurence Brockliss argues, does not have its origins in the US, but in the medieval European universities where students and teachers lived, worked, and studied together in a “cloistered environment.” Yet, the comprehensive planned modern university campus, or what Thomas Jefferson called the “Academical Village,” is primarily an American phenomenon, and the college towns identified in present work all have in common a university with a campus structure.

In its instantiation as an American phenomenon, the college town, is a community that is heavily dependent on the university it hosts. It is a particular type of small town, one whose population is dominated by university faculty, students, and staff. College towns tend to differ from other towns and cities in their respective regions. That is, although many American college towns are situated in remote areas, the young and diverse population, the highly educated work force, the general absence of heavy industry, and the existence of cultural amenities, many of which are characteristic of large cities, set them apart from the rest of the country’s small towns. College towns have characteristics in common both with small towns and with cities: For example, in terms of population, rural/suburban setting, and most of the infrastructure, they are comparable to other kinds of small towns. However, in terms of culture and education, they are more comparable to cities. It should be noted, however, that colleges differ in terms of size, mission, degrees and fields of study, entrance requirements, tuition costs, etc., such that they attract different kinds of students and faculty who, in turn, “shape the character of the towns in which they are located” (Gumprecht 2008, 22).

Modern houses in college towns are usually the result of a specific set of conditions, especially in neighborhoods near the universities: It is reasonable to speculate that several faculty members in these small towns were pioneers in their fields at the time. It can be argued, too, that innovative people want to be seen as risk-takers, and some may have wanted to express this quality by building a house in an unconventional style (Brandon and Lu 2008). In a study of Urbana, Illinois, John Jakle observed that faculty members were more likely than other townspeople “

> to own houses that were architecturally distinctive as a way to set themselves apart as an ‘educated gentry class’ (Gumprecht 2008, 99).

Furthermore, general awareness of the modern movement through an architecture program might be another important condition in towns where social circles in which people are very connected to each other are likely to exist. This is in addition to the direct relationships between the architects and their clients, the latter of whom were also faculty members in some cases. Most college towns have at least one older neighborhood near campus that is home to large numbers of professors, for example, the College Heights Historic District in State College, PA. In fact, nearly half the houses Hajjar designed in the State College area are located in this neighborhood, which expanded during the mid-twentieth-century period.

The college towns in the present study are generally relatively small, and many are located in rural areas. Although beyond the scope of the present paper, studying the sub-culture context of college towns is important to

understanding the architecture produced in that context. The shape grammar technique is foundational to the study as a way to trace the formal and functional effects (and similarities) of European modern architecture and American traditional architecture. However, to describe some of the shape rules, a consideration of local aspects is also necessary to determine the relationship between those effects and the immediate local context.

2.0 FACULTY-PRACTITIONERS

2.1. William Hajjar in State College, PA

Abraham William Hajjar, known professionally as A. William Hajjar and as “Bill” to his friends, was born in 1917 in Lawrence, MA. The youngest of a large immigrant Lebanese family, he left the family’s grocery store business in 1936 to study architecture at the Carnegie Institute of Technology (now Carnegie Mellon). Having received a bachelor of architecture degree from Carnegie (1940) and then a master’s degree from the Massachusetts Institute of Technology (MIT) (1941), he joined the Department of Architecture at the State College of Washington (1942). A few years later (1946), he moved to State College, PA, to join the architecture faculty at the Pennsylvania State College (now Penn State) where he initially focused on securing tenure. As a tenured professor, he practiced in the local area for 11 years beginning in 1952, designing and building thirty-three single-family houses in the area, all of which incorporate many of the shapes, rules, and features of both European modern architecture and traditional American architecture. This period came to an end in 1963 when on a leave of absence from Penn State, Hajjar moved to Philadelphia to collaborate on projects with Vince King, a friend from MIT and a successful architect in the city.

The author has explored Hajjar’s life and practice in detail elsewhere, noting that though Hajjar initially trained with the conventional architecture program offered at the Carnegie Institute, later at MIT he was supervised by Lawrence Anderson, “a longtime bastian of the French approach” at the institution and “instrumental in bringing in modernist thinking” (Alofsin 2012, 115). Hired by MIT in 1933, Anderson served as head of the Department of Architecture from 1947 to 1965 and as dean of the School of Architecture and Planning from 1965 until he retired in 1972. He was one of a few instructors at MIT in the 1930s who pushed the school’s teaching philosophy towards modernism. He introduced a new system for reviewing the students’ work that relied on inviting outside critics to MIT to participate in the process of evaluation and criticism. Walter Gropius and Marcel Breuer—two pioneering figures of European/Bauhaus modernism who were teaching at Harvard at the time—were frequently invited to MIT for exactly this purpose. Thus, MIT’s architecture students (including Hajjar) were introduced to the philosophy of modern architecture expounded by these two architects (Anderson 1922). A simple visual comparison of houses designed by Hajjar and houses designed by Gropius and/or Breuer clearly shows this influence (Figure 1).

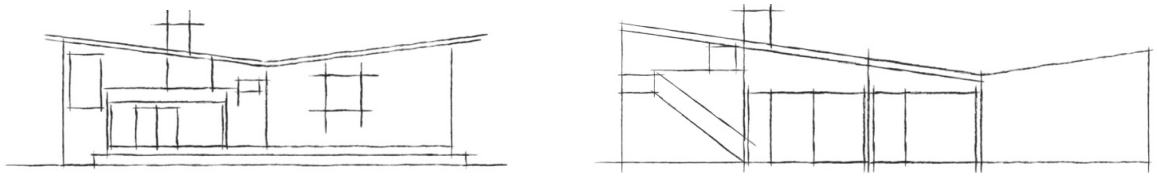


Figure 1: Diagrams of Hajjar’s Hansen House in State College, PA, 1956 (left) and Marcel Breuer’s House in the Museum Garden, MoMA exhibition of 1949. Source: (Author 2024)

Hajjar’s initial work in the State College area was mainly in the College Heights neighborhood situated immediately northwest of the Penn State campus and in the Holmes Foster neighborhood situated to the southwest of the campus. Some of the houses he designed in these neighborhoods, especially the earliest houses, consist of a core “shoe box” design element. The shoe box could be long or short and parallel with or perpendicular to the main road, and most have a low-pitched roof, whether symmetrical or asymmetrical. In addition, the houses usually have a garage (mostly with a flat roof) connected to the main house with a breezeway, although by now many of the breezeways have been altered to accommodate an enclosed addition.

Many of the houses he designed in the area with its special topography and small lots are organized with the entryway and any extension halfway between the upper and lower levels. This can be read as an adaptation of the mid-century split-level effect. However, although in section and in façade, there are similarities between Hajjar’s architecture and mid-century split-level houses, in terms of the interior planning, design, organization of the fenestrations, and the slope of the roof, there are differences. For example, Hajjar’s interior planning leans more towards a modernist idea of an open plan, especially in the public part of the house (living room-dining room-kitchen). Specifically, typical mid-century split-level houses still had a room organization with the living room facing the street, whereas Hajjar’s designs were open with the kitchen facing the street and the living room at the back of the house with large openings between the various functional areas (Figure 2).

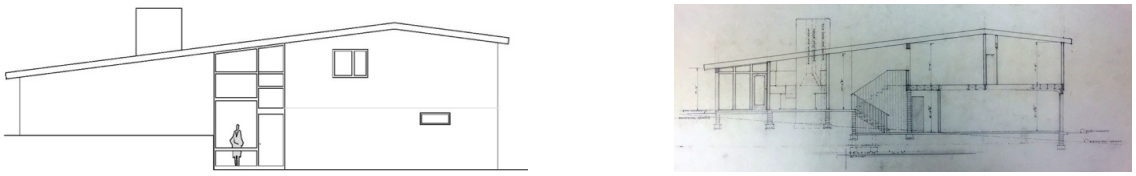


Figure 2: Reproduction of the front elevation of the Eakin Residence, and Hajjar’s section drawing for the same house, as built in 1955 in State College, PA. Source: (Author 2024), left, and (Penn State Special Collections Library), right

Through a consideration of the volumetric relationship, spatial organization, and main features of Hajjar's single-family houses in the area, five subtypes in his plans have been identified (Figure 3): (1) tri-partite organization, where a breezeway connects the garage to the inhabitable space, the lower floor hosts the living areas, and the upper floor the sleeping area; (2) split-level organization, where the sleeping area is a half floor above the living area; (3) butterfly organization, where a cross-shape or U-shape plan prevails; (4) compact organization, where a square-shaped plan reflects Hajjar's idea of a core area; and (5) linear organization, where two square-shaped plans form a rectangular/linear plan. In addition to the volumetric relationship and spatial organization, the way in which the day-time and night-time activities are separated in Hajjar designs is significant as a modernistic feature learned from Marcel Breuer's bio-nuclear designs of 1943.

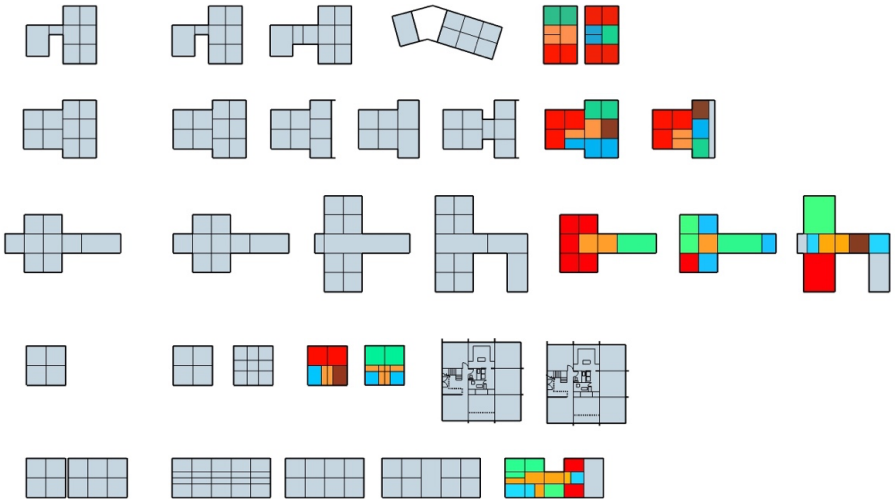


Figure 3: Diagrams showing subtypes of Hajjar's plans. Source: (Author 2024)

2.2. William Caudill in College Station, TX

William Wayne Caudill, also known as "Bill," was born in Hobart, OK, in 1914. He received his bachelor's degree in architecture from Oklahoma A&M College (OAMC, now Oklahoma State University) in 1937 and a master's degree in architecture from MIT in 1939. During his time at OAMC, the architecture world was split between the schools of traditionalism and modernism. Caudill would later write:

> Some of us radical types were pressing for a new age of architecture based on logic and technology.… Oh, how some of us fought for the acceptance of modern forms. Admittedly, we didn't know why they were like they were. We simply wanted change (Kline & Savage 2014).

According to Caudill, the modernists at OAMC could be divided into two camps: those who followed Swiss-born Le Corbusier and those who followed Frank Lloyd Wright. Caudill fell in the latter camp, and some of his later designs show this influence. As he recalled, much of his time in the design studio was spent arguing about philosophy instead of learning to design. While at OAMC, Caudill worked under Philip A. Wilber (1896–1974), head of the college's architecture department. After graduation, he worked for a year with his mentor at the latter's office in Stillwater. Caudill later collaborated with Wilber on the designs for Huston and Washington elementary schools in Blackwell, as well as schools in Stillwater, including the award-winning Westwood Elementary School and C. E. Donart High School, completed in 1951 and 1960, respectively. Caudill was not satisfied with the quality of his design work compared to the best in his field. To rectify this deficiency, he received a scholarship to attend MIT, and graduated with a Master of Architecture degree in 1939. His experience there was much different than his years at OAMC. At MIT, his studies focused on the real world of design, where students tried to solve problems and, as he wrote, "search[ed] for the best functional and aesthetic solution. "He seemed to be a proponent of the "community-based" design approach, emphasizing collaboration with the future users of the buildings.

For his thesis at MIT, Caudill developed an idea for a school building program for Stillwater, Oklahoma. In his thesis, he asserted that public buildings belonged to the people and, therefore, should be made available for their use. Caudill's thesis would later pay off, as his firm was hired to design eleven buildings for and additions to Stillwater's schools. In fact, among those buildings/additions was a community high school envisioned in the thesis. The school was built on the very location that Caudill had selected for it some twenty-some years earlier.

After leaving MIT, he taught architecture at Texas A&M (College Station) and served as a research architect for Texas Engineering Station where he wrote the groundbreaking bulletin Space for Teaching (1941). In 1946, he and John M. Rowlett started an architecture firm in Austin, TX, subsequently moving to College Station where they also taught at Texas A&M. In 1948, Wallie E. Scott joined the firm, which then became known as Caudill Rowlett Scott and Associates and later as CRS. The firm briefly had a branch office in Oklahoma. In 1958, its headquarters moved from Bryan, TX, to Houston and eventually became one of the nation's largest architectural and engineering firms (Oklahoma Historical Society). While Caudill's research and practice were focused on school design, he and his firm designed a few houses in the College Station-Bryan area that represent hybridity between European modernism and American traditional architecture (Figures. 4 & 5).

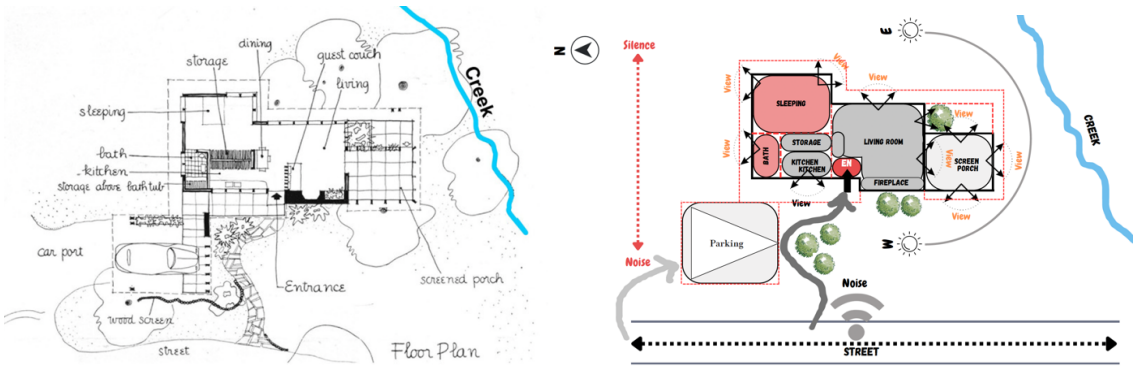


Figure 4: First Caudill House designed by William Caudill, Bryan, TX, 1946: floor plan (left) and formal and functional analysis (right). Source: (Texas A&M CRS Collection), left and (Author 2024), right

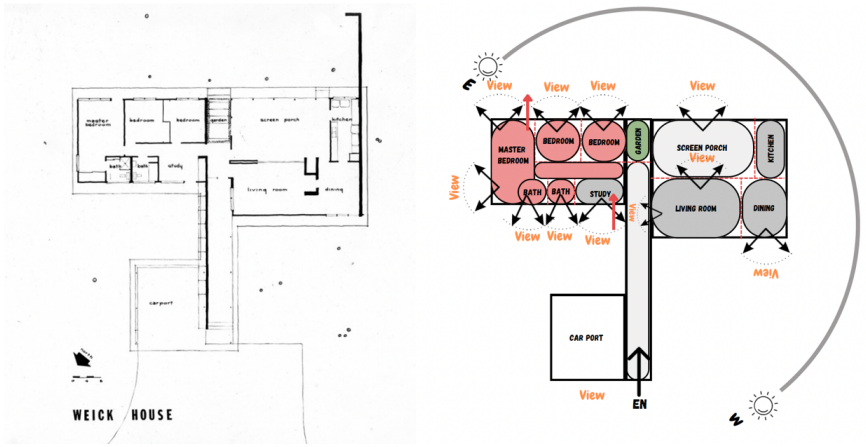


Figure 5: Murdock House designed by William Caudill, Bryan, TX, 1948: floor plan (left) and formal and functional analysis (right). Source: (Texas A&M CRS Collection), left and (Author 2024), right

2.3. Edward Olencki in Ann Arbor, MI

Born in 1922 in Chicago, Edward Olencki attended the Illinois Institute of Technology (IIT), where he received both his bachelor of science degree in architecture (1944) and his master of science in architecture (1949) under Mies van der Rohe. During his time at IIT, Olencki worked as a draftsman and later as a designer for Mies in Chicago from 1943 to 1948. He then joined the University of Michigan faculty in 1948 and continued to teach until his retirement in 1987. He primarily taught courses on construction materials and methods, comprehensive architectural design, and furniture design.

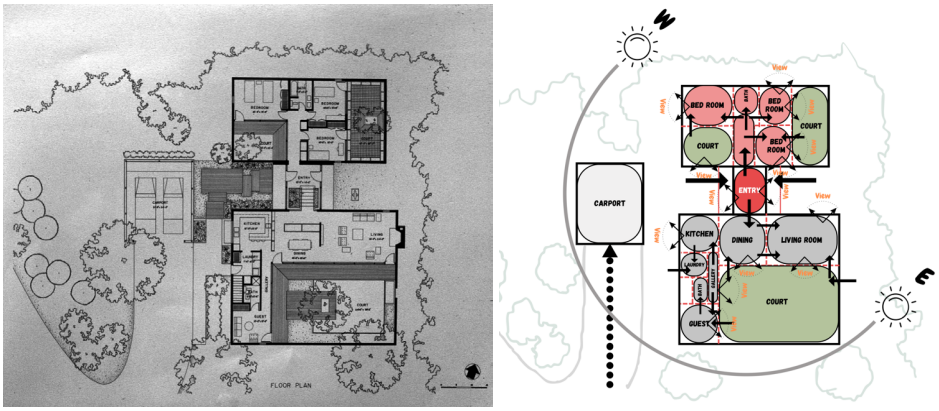


Figure 6: Eaton Residence designed by Olencki & Albano in Ann Arbor in 1962: floor plan (left) and formal and functional analysis (right). Source: (University of Michigan Digital Collection Libraries), left and (Author 2024), right

Olencki's research interests focused on modern church architecture. During his time at Michigan, Olencki also ran an architectural firm, Olencki & Albano, designing homes, churches, and commercial buildings. His partner, Joseph Albano, a graduate of the Armour Institute (later IIT) and Northwest University in Chicago, had also studied with Mies van der Rohe at IIT. He began teaching at the University of Michigan in 1947. One of Olencki & Albano's most famous designs in the area, the Professor and Mrs. Leonard Eaton Residence clearly shows the influence of Mies in its use of materials and certain design elements (Figure 6).

3.0 SHAPE GRAMMAR AND ANALYSIS OF HYBRIDITY IN ARCHITECTURAL DESIGN

Shape grammars in computation are a specific class of production systems based on an initial shape, or set of finite shapes, and transformational shape rules (Stiny & Gips 1971). Since the 1970s, as a design computation method, the shape grammar concept has been used in architectural analysis when a pattern of design characteristics or a stylistic repetition of shapes in architecture is evident. This method has been used to analyze examples of historical architecture, such as the Palladian villas by Stiny and Mitchell, Frank Lloyd Wright's Prairie houses by Koning and Elizenberg, bungalow houses by Downing and Flemming, Queen Anne houses by Flemming, Alvaro Siza's houses at Malagueira by Duarte, and many more. Given that the work of our faculty-practitioners shows strong evidence of shared shapes and transformation rules, the shape grammar methodology constituted an appropriate way to test the hypothesis.

Shape grammars developed to analyze houses designed by some of the three faculty-practitioners in their respective college town are published elsewhere. The present paper focuses on using shape grammar to compare and contrast distinctive design languages, in this case, European modernist and American traditional architecture, in order to identify the hybrid-style homes that faculty-practitioners created in specific local contexts as part of the unique style of college town modernism. As an example, Hajjar's grammar will be used to showcase the way in which shape grammar can be used in the process of comparing and contrasting architectural styles/languages. A detailed account of the development of the grammar for Hajjar's work is available in a previous paper by the author (Hadighi and Duarte 2018). As explained in that paper, the grammar was developed based on five subtypes identified in section 2.1 (Fig. 3). Further, the grammar encompasses four groups of rules: (1) rules that capture the way in which Hajjar situated his houses on the lots; (2) rules that describe the formal relationships between mass volumes; (3) rules that describe the way in which the interior space is divided into smaller rooms or spaces and the way in which functions are allocated; and (4) rules that generate details such as wall thickness and the placement of closets.

During the preliminary study, Hajjar's architecture, like that of his classmates at MIT, was found to reflect the influence of Gropius and Breuer. Therefore, a grammar was developed to analyze residential houses designed and built in the United States by Gropius and Breuer—in the same way and with the same level of detail as the Hajjar grammar. In addition, as can be expected with all architects, the context in which Hajjar practiced also influenced his work. To study single-family domestic architecture designed in traditional styles in the area, it is instructive to explore the College Heights Historic District, a national historic district located north of Penn State's University Park campus where most of Hajjar's works are located. In this neighborhood, most of the houses constructed in the 1920s and 1930s are built in bungalow, colonial (Dutch and Georgian), colonial revival, Georgian revival, and four-square styles. Of these architectural styles, two interior plans are particularly popular in the neighborhood: a four-square organization and a four-room organization with a hallway in the center, the latter of which is very similar to the organization of Hajjar's first house in the area. To analyze the traditional houses of the context, a grammar was developed in the same way and with the same level of detail as the Hajjar grammar.

In order to compare Hajjar's architecture in State College with both single-family houses designed by Gropius and/or Breuer in the United States and the traditional houses in the context, three strategies were identified: (1) compare the rules of the grammars; (2) compare the derivations of similar houses using each of the three grammars, and (3) use one grammar to generate a house from the corpus of another grammar. The use of these strategies to determine the extent of a house's similarity to modern and traditional architecture is further described elsewhere (Hadighi and Duarte 2021). Figure 8 shows the comparison of selected rules of the three grammars divided into different categories, e.g. rules for volumetric organization, rules for dividing the inhabitable space, rules for private vs. public spaces. Although the main purpose of this comparison was to analyze the qualities of the faculty-practitioner's architectural language and to determine how it reflects the influences of traditional American architecture and European modern architecture, the shape grammar methodology provides a way to quantify these influences (Figure 7).

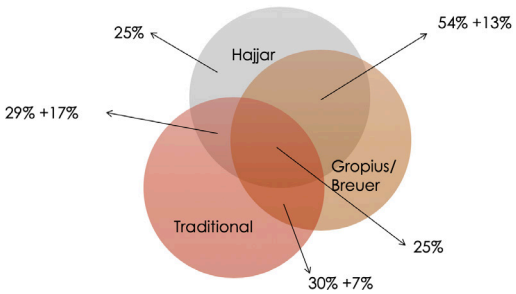


Figure 7: Similarities between the three grammars. Source: (Author 2024)

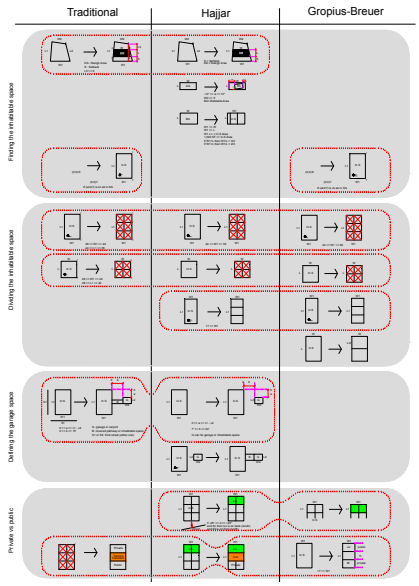


Figure 8: Comparison of the findings of the inhabitable space rules, dividing the inhabitable space rules, defining the garage space rules, and defining private vs. public rules of the three grammars. Source: (Author)

The second strategy used to verify possible similarities between shape grammars is a step-by-step comparison of their derivations, in this case between those of a house designed by Hajjar, a house designed by Gropius–Breuer, and a house from the traditional context. The author has explored this approach in detail elsewhere and shown how a step-by-step comparison of the derivations of houses generated by two grammars can explain similarities between the rules of the two grammars and the influence of one architectural language on another (Hadighi and Duarte 2021). The comparison using this strategy revealed the same qualities and quantities shown in the previous step (Figures 7 and 8).

The third strategy for comparing grammars is to use one grammar to generate a house in the corpus used to derive another grammar. For example, the grammar for Hajjar's houses can be used to derive a Gropius–Breuer house and then the derivation and an original Gropius–Breuer design are compared with each other. Figure 9 shows the derivation of a house with a layout as close as possible to Hajjar's Snowdon House (Figure 10) generated by the traditional grammar.

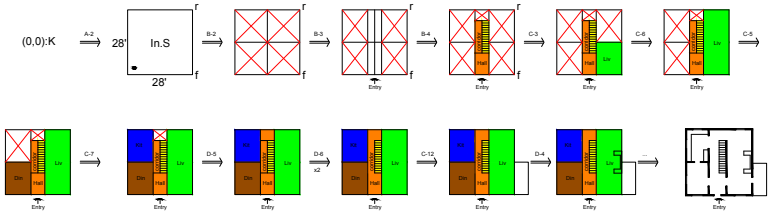


Figure 9: Derivation of a house with a layout as close as possible to Hajjar's Snowdon House using the traditional grammar. Source: (Author 2024)

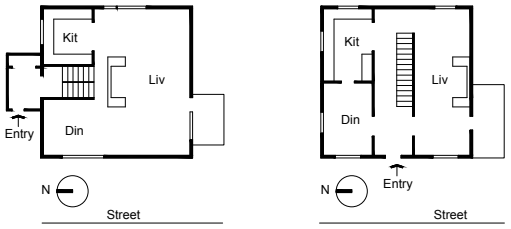


Figure 10: Hajjar's Snowdon House (left) and a house with a similar layout generated using the traditional grammar (right). Source: (Author 2024)

It is certainly the case that similarities in relation to the size of the inhabitable space and to some extent the proportions and allocation the interior functions of the rooms, as well as differences in the openness of the interior layout and the interior circulation reflect similarities and differences between the rules of the grammar for Hajjar's work and the grammar for traditional houses in the area. However, it remains important to understand that these similarities and differences relate to similarities and differences in lifestyle between the two periods. For instance, the kitchen and the dining area are smaller in Hajjar's Snowdon House than in the house generated by the traditional grammar, perhaps reflecting a change in family size between the two periods. On the other hand, the living area is larger in Hajjar's house than in the house generated by the traditional grammar, perhaps reflecting a change in the idea of social relationships in the mid-century United States.

The same strategy of generating a similar house through a different grammar is used to generate a layout as close as possible to a Hajjar design with the Gropius–Breuer grammar. For this purpose, Hajjar's 1955 Eakin Residence, a split-level house with the garage located at the ground level of the bedroom volume, is compared with a house with a similar layout generated by the Gropius–Breuer grammar (Figure 11).

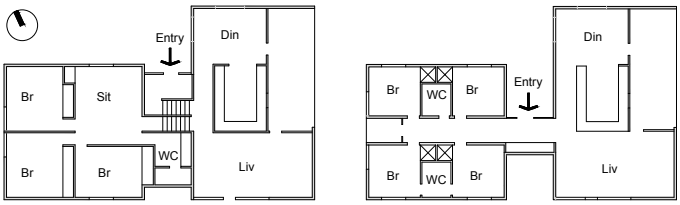


Figure 11: Main floor plan of the Eakin Residence designed by Hajjar and generated by the Hajjar grammar (left) and the plan generated by the Gropius–Breuer grammar as close as possible to the Eakin Residence's layout. Source: (Author 2024)

Both the Hajjar design and the design generated by the Gropius–Breuer grammar reflect a binuclear layout. However, in the Hajjar grammar, the connecting part, usually the breezeway in Hajjar's designs, is an inhabitable space occupiable by interior functions, whereas in the Gropius–Breuer grammar, the connector is mainly a transitional space between the public and private parts of the house. In the private part of the house, the Hajjar grammar can easily generate a family room or what was called the sitting room by Hajjar, whereas the Gropius–Breuer grammar does not generate that space but instead offers a wider corridor, which itself can serve as a gathering space within the private part of the house. Hajjar's Eakin Residence is a split-level house, similar to many other houses situated in the hilly part of the neighborhood. As no houses by Gropius and/or Breuer include a staircase within the connector, the Gropius–Breuer grammar cannot generate this feature, and therefore, cannot produce a split-level organization.

A comparison of the rules of the grammars identifies technical rules for generating layouts that can be very similar (e.g., rules for converting a line to a wall). However, the comparison also brings to light rules with similar shapes but different descriptions, which predominantly reflect variations in building technologies (e.g., the maximum length of a beam) and building codes (e.g., the extent of setbacks). There are also rules specific to each grammar and rules that are very similar in all the grammars, the latter of which can explain similarities between and the influences of modern architecture and traditional architecture on the work of the faculty-practitioner (in this case Hajjar).

In Hajjar's architecture (similar to that of the other faculty-practitioners), the allocation of interior functions shows similarities with that of the traditional architecture. However, the flow of spaces and the openness of his interior planning lean towards modern principles of design. This is also true of his attention to the idea of energy-efficiency, reflected in, for example, his positioning of the fireplace as a main design aspect of the interior circulation rather than as a feature on an exterior wall. This hybridity between European modernist and American traditional architecture was a key to faculty-practitioners' success in practicing architecture in American college towns in the mid-twentieth century. Of course, changes in people's lifestyles and the cultural and socio-economic changes after World War II in the United States led to a reassessment of the principles of residential architecture in the country to which contractors and architects nationwide duly responded.

CONCLUSION

Overall, a new style is identified and its influence explored through the shape grammar method: The hybrid-style homes that faculty-practitioners created in specific local contexts in the mid-twentieth-century period brought modernism to the suburbs and are part of the local communities we know and enjoy today. Through this investigative story, a unique architectural style is revealed—what may be called "college town modernism"—and the shape grammar method is introduced as a complementary tool for architects and historians to use in identifying and analyzing hybridity in architectural design.

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The Design and Fabrication of the Bleachery Heritage Project

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ABSTRACT: This paper outlines the design and fabrication of a cultural heritage landscape project located in Rock Hill, South Carolina. The project involves the transformation of an existing median into a commemorative linear park, located on the former site of Rock Hill Printing and Finishing Company. Through an overview of the design methods and processes, this paper explores the importance of combined knowledge and methods from generally siloed topics of community engagement, construction technology, and digital fabrication.

KEYWORDS: cultural heritage, landscape, digital fabrication, community engagement, interaction design

1.0 PROJECT OVERVIEW

The Bleachery Heritage Plaza is located on the site of the former Rock Hill Printing and Finishing Company, known locally as “The Bleachery”, which was once the largest textile printing and finishing company in the world (Figure 1). The project provides a living memorial: to the Bleachery, its employees, and the sense of community that surrounded it, while also forming a new urban room for the city, a plaza that becomes “a monument to everyday life within a memory landscape” (Spencer 2020). The site is located at the center of University Center, a 23-acre mixed-use development.

The three goals for the project were driven by the community and the client, Rock Hill Economic and Urban Development, a local non-profit organization representing community interests of the city while promoting jobs and supporting urban growth. The first design objective for the project was to create a commemorative place that honors and fosters an appreciation for the history of the site. A second goal was to incorporate preserved historic roller textile printing machine parts and the original archway entrance from the Bleachery in the project. Lastly, a third design objective was to enhance the visitor experience by inspiring a deeper sense of place and community.



Figure 1: Aerial view photograph of a median transformed into the Bleachery Heritage Plaza. Source: (Dickey 2023)

2.0 COMMUNITY, HISTORY, AND PLACE

To address these objectives, during the first three months of the project, we, the design team, conducted community engagement workshops to understand more about the residents, site history, and place. The first session involved storytelling workshops where we interviewed 57 community members, gathering their stories which were later compiled as a commemorative set of audio and video recordings linked to QR codes on site.

During these interviews, we heard stories about employment, about how the Bleachery at its height employed one-third of the population of Rock Hill. We heard stories about the community, and about the many benefits the Bleachery provided for its employees and their families, including Christmas parties and gifts, park events and picnics, and a textile league baseball team. We heard stories about families. Jim Gordon told us of how his father, who started working at the Bleachery in 1932, worked there for 55 years, which was his only job other than when he went into service during World War II. Jim explained, when talking about his sister Susan, “People used to think she had the largest shoe collection because my father would bring home pieces of fabric from the Bleachery and Susan would take the pieces of cloth and glue them to her shoes to match her dresses.”

Also, like many stories of humanity throughout history, the stories shared involved celebrations, milestones, work, and home, but we also heard incredible stories of brave people willing to take personal risks. Willie James Ellison shared with us the story of his father Reverend Dr. Leroy Ellison who started working at the Bleachery in 1954. After the federal Equal Employment Act (1966) was passed, he told of how his father rallied 300 workers in 1972 to come together with him in support of filing a lawsuit, fighting for equal pay for women and black employees. Willie described the horrific threats and backlash that followed. He also described the weighted undertaking of going against the Bleachery at the time, exclaiming, “It would be like one of Amazon's employees today filing a lawsuit against them." Rev. Elison later won the federal court case hearing in 1975 and continued to fight inequities as an employee until 1980. When discussing the plans for this project, Willie emphasized, “You have the opportunity to display to the world we existed at that time and that we made changes, not for ourselves, … but like my father,” he said, “he didn’t do anything for himself but was doing it for those who would come after him.”

These stories influenced and shaped the design in several ways. For one, they provided the team with an understanding of the site and community by helping shape a design agenda that would not only commemorate the residents and their stories but also provide community-informed ideas of public space that is shared and realized through new construction. Additionally, the project became grounded in not just preserving history but also striving to provide an architecture where the lessons from those histories could guide the future of the place. Lastly, the video and audio recordings of stories were later referenced on QR codes and included on five historic interpretive signs on-site (Figure 2).

With the immense of content gathered, we selected and curated the content for the signage based on the aspirations portrayed by the community and the following shared goals outlined in the city’s interpretive foundations plan: (1) Visitors will report feeling interested in learning more about the Rock Hill community and their histories as a result of their interpretive experience at University center (2) Visitors will feel empowered to face their challenges with personal strength (3) Visitors will know that Rock Hill was a focal point during the Civil Rights movement, and The Bleachery featured prominently in the evolution of the African-American experience in Rock Hill (4) Visitors will know that Rock Hill has been and continues to be a community of great diversity (5) Visitors will feel a sense of being united for a common purpose while at the University Center (Conservation by Design 2018).



Figure 2: Interpretive signage with QR codes linking to an audio and video record of stories gathered from community members during community engagement workshops. Source: (Dickey 2023)



Figure 3: View through the textile roller machine part looking at a rocking chair. Source: (Dickey 2023)



Figure 4: View of textile roller printing machine part located in the Bleachery Heritage Plaza Source: (Dickey 2005)

3.0 SITE, LANDSCAPE, AND URBAN DESIGN

Working within the objective of creating a commemorative place and within the client's constraints and confinements of a traffic median site, the design team proposed the transformation of the median into a commemorative plaza and sculpture garden. The design weaves the landscape with historic roller printing machine parts, rocking chairs resembling those machines, and a former Bleachery building archway standing anew as a gateway entrance to shared public space (Figure 3 and 4).

Budgetary constraints along with the ambitions for the project lead to prioritizing the transformation of the site into a plaza with a landscape buffer that separates pedestrians from vehicular traffic. These landscape and urban design strategies for the project learn from the median site conditions of La Condesa along Amsterdam Avenue in Mexico City and the High Line in New York City, using trees and tall grasses as a spatial divider to define zones and boundaries between circulation and areas for street furniture and historic objects (Figure 5).

A hexagonal planar grid, divided into six triangular quadrants, provides a means for ordering space through the delineation of hard and softscape elements and the division of slow paths with undulating spaces for objects and furniture. Additionally, the triangular quadrants within the hexagon grid inform a pattern logic for the stamped pavement design (Figure 6). The team designed and fabricated custom triangular concrete stamps, using patterns printed on fabric at the Bleachery. These stamped patterns run along the pathway of the plaza, an idea conceived by community members during an ideation community engagement workshop. The pattern design for these stamps was later developed by a local Rock Hill high school art class through a lesson on pattern and tessellation taught by the design team. The production of the stamps involved CNC-milled foam molds produced from a digital 3D model, coated with wax protectant then used to cast custom urethane rubber concrete stamps. These stamps were later delivered on-site to the contractor, allowing for a range of customization within typical means and methods of construction.



Figure 5: Textile machine parts, weathering steel signage, landscape buffer, and rocking chair in Bleachery Heritage Plaza. Source: (Dickey 2023)



Figure 6: The team designed and fabricated custom concrete stamps informed by patterns printed on fabric at the Bleachery. These were used to stamp patterns along the pathway of the plaza. Source: (Dickey 2023)

4.0 STREET FURNITURE AND FABRICATION

While the historic elements and signage provide reference to the history, and the site design provides delineation of space for an outdoor room, the incorporation of interactive street furniture invites visitors to enter, playfully engage, and participate in the site. The community in ideation workshops expressed a reoccurring desire for interactive elements on the site so visitors might actively engage with its history. Some of such requests included ideas for outdoor kiosks and screens; however, working within the budget and towards the goals, the design team prioritized the landscape design of the plaza and developed conditions for interactive elements with the design of the street furniture. The multi-occupant rocking chairs are an invitation for visitors to develop and contribute their own stories to the collective experience of Rock Hill by actively and publicly engaging in public space (Figure 7).



Figure 7: Rocking chair with textile printing machine in the background. The design of the street furniture extracts visual and kinetic attributes from the neighboring machine parts. Source: (Dickey 2023)

Community conversations for the rocker design explored how the chairs could extract visual and kinetic attributes from the neighboring machine parts and invite users to interact with each other and the site. Likewise referencing the region of the project, these discussions drew from the Southern United States cultural canon of rockers arranged on traditional porches and patios, like those of the surrounding historic mill homes nearby, converting the idea of a front porch into a shared space and public threshold to the surrounding new development. Galen Cranz in her book, *The Chair: Rethinking Culture, Body, and Design,* references the rocking chair history when writing, “The rocker is responsive to the body first and status second, [...] The rocking chair is an American invention. An ingenious inventor or perhaps more than one, attached rockers to chair legs around 1760 [...] So we must assume that rocking chairs were a vernacular taste, not an elite one. Yet the rocker became acceptable to those who could afford parlors, probably because of its familiar materials and homegrown connotations” (Cranz 2000, 49). Such familiarity and opportunities for interactivity excited the client along with the visual language the chairs shared with surrounding historical elements.

When developing the design, the team drew from precedents including Swing Time by Howler + Yoon in Boston, Magis Spun Chairs by Herman Miller along Magnificent Mile in Denver, and the Chicago Biennial installation titled, *The End of Sitting* by RAAAF. While the Swing Time and Spun Chairs explore playful kinetic chairs in public spaces, the RAAAF project looks at postures and positions of the body as a means for carving profiles within the furniture (RAAAF 2015). Also, the development of the chairs explored the relationship between form and performance referencing the external geometry based on the rocking motion and the internal form based on the form of the body. The design team studied the external form through a series of iterative scale 3D printed and laser cut models and later a full-scale prototype to test geometry and motion. The design of the internal form of the rocker involved the study of the body at various positions and postures. Profile curves based on a relaxed body position of multiple occupant bodies provide a carved opening for sitting within the thickened face of the rocker.

The fabrication involved a wood frame clad with weathering steel to blend with the surrounding rusted elements in the landscape. The team developed an approach for fabrication by using high-grade plywood CNC milled and layered for the front and back faces. These two faces were then supported with an internal wood framing. The weathering steel cladding involved precision laser-cut panels. The side steel panels were machine-rolled with a bending radius to match the curvature of the frame. To prevent any case of the rockers tipping, the design team developed an anchor system that would allow for motion but prevent overturning. The anchor works like a pin-in-slot mechanism, with a linear steel pipe acting as the pin and the slot cut from two parallel faces of the steel anchor box, with its opening shape informed by the path of motion (Figure 8-9). The slots are laser cut out of steel plates and then stitch-welded together to form an anchor box that is j-bolted to the concrete slab on site, while the pipe is connected and fitted within the internal frame of the rocker allowing it to dynamically rock between the slot openings. Lastly, the weathering steel cladding anchors to all sides of the rocker covering the wood frame (Figure 10).



Figure 8: Prototype of rocker and anchor box for testing the prevention of overturning while allowing for rocking motion. Source: (Dickey 2023)



Figure 9: View of rocker anchor box with pin and slot to allow for movement. Source: (Dickey 2023)



Figure 10: Rocking chair in progress fabrication photograph of wood framing and steel cladding. Source: (Dickey 2023)

CONCLUSION

In her book, “Belonging: A Culture of Place,” Bell Hooks writes:

> We are born and have our being in a place of memory. We chart our lives by everything we remember from the mundane moment to the majestic. We know ourselves through the art and act of remembering […] Paying tribute to the past acts as a resource that can serve as a foundation for us to renew our commitment to the present” (Hooks 2019, 9).

This idea of looking backward to improve upon ways of moving forward has been at the core of the Bleachery Heritage Project since we were first shortlisted to work on it in 2019. We started the project with ideas of designing a place, but we soon realized it was less about place making and more about place expressing. So, as an act of design for expression, we gathered the stories of the people who have stood, gathered, and worked on the ground where the project sits today.

Speaking with members of the community, we learned there is evidence of the many ways the people of Rock Hill have adapted to changing times. Whether in the story of Rev. Ellison working to develop the Bleachery into a place that further respected human rights or in the story of the Rock Hill Buggy Company (also formerly located on the site), which reinvented itself by shifting from production of horse-drawn buggies to the production of Anderson motor cars or in the story of today, a modern re-imagining of a historic textile site. It is clear in all these cases that the social fabric of Rock Hill demonstrates resilience and an unbreakable spirit in times of challenge and change.

At the Bleachery Heritage Plaza, the act of construction is a communal act of un-forgetting. At its best, the plaza tries to serve its constituents, while telling stories of the past, inviting visitors to enter and experience them, to slow down and notice what once was (Figure 11). The excerpt below is from our dedication speech for the Bleachery Heritage Plaza at the opening ceremony:

> When entering the plaza, we ask you to take a moment of pause in your movement, to find a stillness, and to notice….
>
> Notice the textile patterns stamped on the ground beneath your feet
> Notice the roller machine parts that employees once ran to produce miles and miles of printed cloth
> Notice the relaxed position of your body rocking in sculptural chairs resembling those machines
> Notice the former bleachery building archway standing anew as a gateway entrance to shared public space
> Notice the signs, scan their QR codes, and listen to the stories.
>
> As you notice and allow for a pause in movement, there in the stillness, you’ll find place
> A place inspired by a deeper sense of community
> A place of unforgetting
> A place providing a renewed commitment to the present
> A place to belong.

Damaris Hollingsworth in “Places and Spaces and the Behavior They Create” explains that architecture can cause interactions that promote belonging. She provocatively states, "When we find belonging, we find home.” Such concepts are often disparaged across our discipline and the connotation of “place” is frequently misappropriated (Hollingsworth 2018). Addressing such topics requires a rigorous engagement and understanding of people. Engaging people and addressing their wants and needs is a process far different from scientific methods and approaches to design, but instead requires “other ways of knowing” engaging in subjectivity, emotion, an often-messy exploration into communal identity, and a not-so-straightforward digging into what constitutes belonging (Frank 2007, 304).



Figure 11: Bleachery Heritage Plaza with rocking chairs, landscape buffer, signage, and historic machine parts. Source: (Dickey 2005)

However, this quest for a public architecture that supports communal identity requires overlapping studies of the social, artistic, and technical conditions of our discipline. Michael Murphey of MASS Design Group similarly articulates the common struggle in architectural discourse and practice to isolate innovative or artistic ventures from social agendas. This grappling is evident in Murphy's statements about letting the clients know they deserve both justice and beauty (Murphey 2019, 30). He explains that there is a point to being an architect in a room full of people with a social agenda. Here, Murphey describes the role of the knowledge set of the architect, such as knowledge of design, materials, space, form, fabrication, and construction, which all help to facilitate conditions that improve the well-being of people.

In practice, forms of design knowledge are not contained in silos of community engagement, cultural heritage, building technology, responsive environments, digital fabrication, and so forth, as we see in academia. Rather design practice involves a holistic approach incorporating multiple formats of design knowledge. Perhaps this paper acts as a reminder of the potential embedded within the convergence of these specialties and asks for a resurgence of overlapping forms of thought recognized as academic contributions. When diverse teams focus on applying design knowledge to engage the community and explore applications for new technologies, only then are novel designs that address people and place made possible.

ACKNOWLEDGEMENTS

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Bridging Cultures: Explorations, Collisions + Considerations of Indigeneity & Design

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ABSTRACT: This research project addresses a long-standing issue in contemporary Environmental design education and practice: the exclusion of Indigenous perspectives in all educational processes, principles, and policies. This one-year research initiative collaborated with three Indigenous Knowledge Keepers as guides and mentors and aimed at integrating indigenous ways of seeing and knowing into curricula and pedagogy within the fields of Architecture, Planning, and Landscape. The initiative was funded by an Indigenous Engagement Grant from the University of Calgary and spanned two consecutive semesters, involving multiple studios and courses, where instructors had the flexibility and support to align their course content with the overarching Indigenous research theme. Roundtable discussions and workshops, led by Indigenous leaders, played a pivotal role in the project. These workshops served various purposes throughout the academic year, including introducing Indigenous Culture, providing design critiques, offering reflections, and allowing for open question sessions. Key to this endeavor's success was the creation of a welcoming and respectful environment. The research recognized the need to treat Western Design and Indigenous cultures as distinct, running in parallel, with the establishment of an ethical space as a secure and safe bridge between them. In bringing Design and Indigenous realms into juxtaposition, and at times collision, the research leaders needed to be supportive and diligent around risks & vulnerabilities, while cultivating opportunities and opening doors to discovery. Despite the participants' initial lack of awareness about Indigenous ways, the guidance of Indigenous mentors, coupled with facilitation by research leaders and participant motivation, led to significant progress in design work that incorporated, respected, and celebrated Indigenous knowledge. This paper narrates the educational journey of this initiative and outlines valuable lessons that promise to positively impact the design education and practice of tomorrow..

KEYWORDS: indigenous, pedagogy, architecture, innovation, ethics

INTRODUCTION

> What is life? It is the flash of a firefly in the night. It is the breath of a buffalo in the wintertime. It is the little shadow which runs across the grass and loses itself in the sunset. – (Crowfoot N.D.)

Design, in our contemporary world, faces a plethora of unforeseen challenges, forces and factors that demand attention and innovation. Paramount in this mix of emergent parameters are equity, diversity, inclusion, and accessibility (EDIA). While the origins of the profession of Architecture, and allied design fields, are rooted in power, politics, and privilege, today we are increasingly called to answer to a broader base of users, to respect a wider range of communities, and to design with sensibility + sensitivity, responding to a different today while anticipating an unknown tomorrow. Essential to understand is that;

> Design has to be extricated from the rationalistic, dualist, capitalistic, and modernist traditions in which it has been enmeshed, and reoriented toward the creation of conditions for other ways of being~knowing~doing (Escobar 2015).

Given the highly pluralistic character of many countries, cities, and communities, it is proving inadequate and unethical to design to a tightly defined demographic, to accommodate only a narrow constituency, or to be driven by short-term agendas. Contemporary design demands an embrace of uncertainty, a subscription to flexibility, and a commitment to continuous reflection, reform, and improvement.

This paper recounts research funded through an Indigenous Engagement Grant in Canada and stands unique in both its ambitions and approaches. The research addresses a deeply rooted problem in Environmental Design education + practice – namely, pronounced, and irresponsible omission of Indigenous ways of seeing, thinking, knowing and being in processes, principles, procedures, policies, and so forth. In a positive and proactive gesture, the research included three prominent Indigenous Knowledge Keepers as guides and mentors in the project: Casey Eagle Speaker, Sandra Sutter, and Tito Gomez. The initiative, a year in duration, involved six+ studios/courses (i.e., Architecture, Landscape Architecture + Planning) in two consecutive semesters – with a goal to have Indigenous culture find places of influence and inspiration within curricula and pedagogy. The Instructors, Mary Ellen Taylor, Mauricio Soto-Rubio, Fabian Neuhaus, Nooshin Esmaeili, Volodymyr Amiot, and Enrica Dall'Ara, were free to determine briefs, content, and directions within the greater Indigenous-centric research/teaching venture. A common thread for all courses, studios, instructors, and students, was participation in community workshops offered multiple times over the research period. These workshops, led by Indigenous Knowledge Keepers, had manifold goals – dependent on location within the academic year – such as the introduction of Indigenous Culture, provision of design critique at pivotal points, proffering of reflections at the end of a semester, open question periods, etc. Through these practices, the climate for the research endeavor, supported by Indigenous Knowledge Keepers, was welcoming, respectful, and assuring. Fundamental to the research were two qualities: an acceptance that Design and Indigeneity were distinct cultures needing to run in parallel (i.e., seeing with 'two eyes'), and awareness that

ethical space needed to be created as a bridge (shared domain) between the two cultures. In bringing Design and Indigenous realms into juxtaposition, and at times collision, the research leaders (both Architecture professors) needed to be diligent around risks & vulnerabilities, while cultivating opportunities and opening doors to discovery. Many participants on the university side came to the project with little awareness of Indigenous ways. Through the kindness and wisdom of the Indigenous Knowledge Keepers, coupled with facilitation by seasoned researchers and the motivation of participants, remarkable strides were made in design work that incorporated, respected, and celebrated Indigenous knowledge. This paper tells the story of this courageous educational journey, and outlines lessons that hold promise to positively impact Environmental Design education and practice moving forward.

1.0 BACKGROUND OF THE TEACHING ENGAGEMENT RESEARCH INITIATIVE

> While there are undeniably wounds, insensitivities, and injustices there are also good intentions, a willingness to know, and some exciting visions for a far better future. (Sinclair, Calliou, Sutter 2014).

History, protocols, and intentions matter when collaborating with indigenous communities. From design studios honoring Indigenous culture, courses including First Nations, Metis and Inuit (FNMI) dimensions, academics serving on key university committees supporting Indigenous communities, and faculty winning awards for commitment to Indigenouscentred teaching + research, the School of Architecture, Planning, and Landscape at the University of Calgary has proven dedicated and committed. While the history of engagement with Indigenous culture within the school is relatively short, the initiatives have nonetheless been many and meaningful. For example, faculty members have been running indigenous-themed studios for several years, such as designs for Aboriginal Cultural Centres at the Centres at the Fort Calgary and University of Calgary sites. They have also engaged in collaborative interdisciplinary studios working with local indigenous bands to address design of commercial, housing, and community projects. Such studios have included FNMI members to guide steps and provide feedback and subscribed to the dictum “Nothing about us, without us.” The school has also been involved in research projects considering a range of Indigenous topics, including shelter approaches and sustainability solutions. At the community level the institution has organized and hosted numerous symposia and lectures, covering a range of topics from Indigenous design thinking and authority in design to sharing the city and social justice. Faculty from the School of Architecture, Planning, and Landscape are recipients of honors recognizing leadership in the realm of Indigenous Culture in environmental design, including a prestigious Rev. Dr. Chief John Snow Award and the University of Calgary Teaching Award for Excellence in Indigenous Ways of Knowing.

The workshops described in this paper serves as a pivotal step in the school's ongoing commitment to embrace Indigenous aspects of design and planning. The initiative represents a cohesive and focused approach to provide a structured framework for the integration of Indigenous ways of being and knowing into the curriculum, and to foster a deeper understanding of Indigenous culture, knowledge, and practices among both students and faculty. By respectfully engaging with Indigenous Knowledge Keepers and emphasizing community involvement, the initiative seeks to create a more inclusive, continuous, and meaningful educational experience. Through the sharing of stories, from both Indigenous and Non-Indigenous perspectives, a shared understanding developed — around our past, our present, and our future.

2.0 METHODS

> We argue that this path will be more successful if we, Indigenous and non-Indigenous alike, can walk together, understand each other, share together, and see through the eyes of the other. (Sinclair, Calliou, Sutter 2014).

Critical to the success of this initiative was the conscious creation of an ‘Ethical Space’, where students, instructors, Indigenous Knowledge Keepers, and the rest of the participants in this initiative felt safe, protected, and supported. An Ethical Space can be defined as condition or state where a culture of empathy, equity and inclusion is openly discussed, agreed upon, and maintained throughout the project. This tactic provides participants with an opportunity to ask any questions without fear of retribution of judgement, to recognize different points of view based on individual backgrounds and histories, and to acknowledge we can all learn from one another. Operating within an Ethical Space allowed the design projects to resonate with Indigenous sensitivities and priorities participants, and more importantly, allowed participants to grow as individuals.

2.1 Two phases – five workshops – six design courses

This project was conducted primarily at the graduate level, with one instructor at the undergraduate level joining halfway through. At the graduate level, the students per class totalled between 9-21 and at the undergraduate level between 90-100. Per semester, there were between 3-4 classes participating, ranging across all three disciplines (Architecture, Landscape Architecture, Planning). Studios and courses explored not only design, but also emerging areas such as land trusts, affordable housing, master planning, advanced technologies, and so forth. Modes of engagement included workshops, storytelling, indigenous expert critique + input, elder knowledge sharing, open question periods, design integration, experiential learning, and student/staff reflections. The workshops comprised two phases, each encompassing three components: imagination, exploration, and reflection. Each phase, and all components, benefited from the guidance of Indigenous Knowledge Keepers, and brought together into communion and conversation both Indigenous and Non-Indigenous communities.

2.1.1 Phase one – getting to know what we don’t know (fall Semester, 2023)

In this phase, the initial focus was on developing an understanding about the two distinct spheres of Indigenous culture and Western design traditions. This part of our journey included historical challenges as well as distinct priorities and goals. It presented an opportunity for the participants to learn from each other within a previously

defined 'Ethical Space'. An opening roundtable event that included faculty, student representatives, and Indigenous Knowledge Keepers provided a chance to consider parallel histories, to gain appreciation of different world views, and to establish common ground. This forum permitted a fulsome critique of the school's historical efforts to incorporate Indigenous Ways of Knowing, while also recognizing necessary steps to succeed moving forward. Building from initial conversations, there were pilot projects that took place within the Architecture, Planning, and Landscape programs. These projects took the form of design studios or other courses, with a goal to meaningfully engage Indigenous communities and explore collective issues. Design studios comprised a signature pedagogy at SAPL - permitting students to tackle complex design problems and develop their own skills and knowledge. Mid-way through the semester, the Indigenous Knowledge Keepers met with faculty and students involved in the three Fall Term Pilot Projects, with a goal to learn, exchange, and improve. The students and faculty involved in the projects came together as an interdisciplinary group to work with Indigenous Knowledge Keepers in an open forum format, where the entire school had the opportunity to listen and participate.

2.1.2 Phase two - reflecting, revising, refining (winter Semester, 2024)

This phase started with a Roundtable intended to reflect on the activities of the previous phase, consider lessons learned, and to provide feedback essential to moving ahead. Participants presented stories from Phase One (Fall semester) - reflections of successes as well as difficulties and challenges. The session involved identifying steps that should be folded into the curricula of the three Winter Term Pilot Projects - one pilot each in Architecture, Planning, and Landscape. Mid-way through the second semester, the Indigenous Leaders met with faculty and students engaged in the respective pilot projects. Through open sharing of obstacles and opportunities, adjustments were made to teaching and learning to improve experiences and strengthen outcomes. At the end of the term, a final Roundtable was held with Indigenous and Non-Indigenous members to reflect on the rich path of discovery, to highlight progress made, and to consider next steps. The conversations of this concluding Roundtable directly contributed valuable knowledge to reforming the School of Architecture, Planning, and Landscape's Strategic Plan. As noted previously, the numerous reflective and community conversations within the initiative had impacted curricular dimensions of the graduate programs dramatically and positively, while also, and more profoundly, shaping curricular content and pedagogy in a new Bachelor of Design in City Innovation (BDCI undergraduate design program.

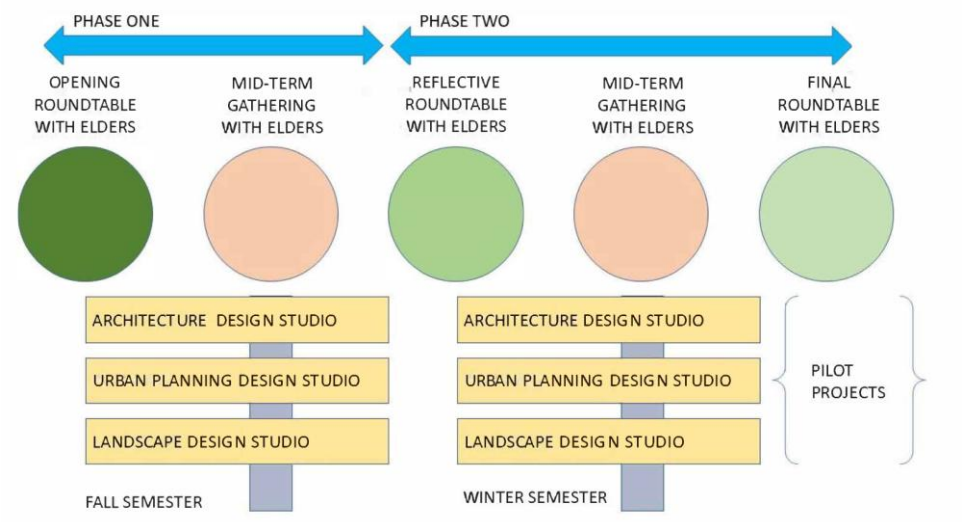


Figure 1: Chart of the Research initiative showing two phases, five roundtables, and six courses.

3.0 TEACHING ENGAGEMENT STRATEGIES

> Our Western design practice is to imitate and to sample what we learn, see and experience in our design education. This practice is counterproductive for decolonizing progress. Source: (Fabian Neuhaus, Interview by authors, 2023)

3.1 Workshop structure

The structure of the proposed activities was an important strategic consideration. There were five workshops conducted over one academic year (September to April) followed by reflection interviews with each participating instructor. Each workshop, save for the final professors' project review session, was four hours long and was structured so that there was an introduction by research leaders outlining the goals, followed by guest speaker sharing, and then an open question period. A key goal was to share, learn, and develop together as we pursued more meaningful curricular composition, content, and outcomes. Researchers Mauricio Soto Rubio and Dr. Brian Sinclair moderated the workshops, while Cathryn John and Kriti Acharya recorded written notes. Out of respect for the wishes of the Indigenous Knowledge Keepers, audio and visual recordings were not permitted. It was also expected that the same three Indigenous Knowledge Keepers (a Treaty 7 Elder, a Metis leader, and a Chippewa-Cree & Tohono O'odham Knowledge Keeper) worked in the project over the course of the grant to ensure continuity, to develop trust, and to nurture the school's ongoing relationship with the Elders. The project was envisioned as incorporating both full community conversations (at the roundtables) as well as more specific explorations within

the curriculum. A key goal was to have faculty and students who worked on pilot projects join with the larger SAPL community to share stories, present learnings, and build knowledge practices together.

These sessions were designed to be less formal, so that students and staff would feel comfortable participating and asking questions. The safety to ask questions without judgement was paramount in assisting students in their understanding of indigenous ways of knowing and being. One of the Knowledge Keepers, Tito Gomez, encouraged students and instructors to treat the question period like an Ask Me Anything (AMA) session where participants put aside fear of insult, and asked the questions that they would otherwise be too afraid to ask. By prefacing the question period in this way, a space of understanding, sharing and empathy was created, while learning was augmented. The guest speakers would begin by introducing themselves and how they grew up, the shared stories they learned and wisdom they had come to know. Through this sharing, storytelling became a method of generating “a space of mutuality that can open up new ways of being in the world” (Barcham 2019). Through this openness, students and instructors were able to glean a deeper, often unfettered, understanding of local indigenous cultures and respectful ways of engaging indigenous communities. The workshops were a response to the calls to action by the Canadian Truth and Reconciliation Commission (TRC) – delineating efforts non-Indigenous peoples need to take to better understand indigenous cultures and move demonstrably towards reconciliation. Through open, honest and empathetic communication, Elders, Knowledge Keepers, students and instructors together cultivated a welcoming environment that empowered participants with the courage to share their stories and accept each other despite their differences. These workshops enhanced the deeply immersive experiential learning in each studio, leaving a lasting and positive impact on the participants.



Figure 2: Workshop with Elders at the School of Architecture, Planning, and Landscape at the University of Calgary.

3.2 The course descriptions

The research project encompassed a range of courses, specifically design studios and design theory courses hailing from the domains of Architecture, Urban Planning, and Landscape Architecture. These courses, while already equipped with their long-established educational objectives, embarked on a unique journey to introduce students & teachers to Indigenous perspectives and ways of seeing and understanding the world. The overarching teaching approach aimed to foster a harmonious blend between Indigenous knowledge and contemporary Western studio culture, ultimately forging a novel teaching methodology. Consequently, studios became dynamic spaces where the realms of design culture and Indigenous culture converged, influencing the creative projects undertaken by students. The courses included the following:

3.2.1 MArch Foundation Design Studio: An indigenous artist live/work studio

This is the first studio in the 3-year MArch program, and therefore, it shoulders the responsibility to define foundational aspects of architecture, its culture, its design process, and its discipline. Part of the learning curve explicit in the pedagogy of a first studio is the development of a consciousness around moving from lived experience to its abstract interpretation within architectural conventions. These architectural conventions collectively form a language that can be consciously manipulated towards the ‘construction’ of design intentions in architectural form. Architectural form, in turn, anticipates lived experience. However, what type of experiences should define an architectural project? This studio invited students to design a live/work studio for a prominent Indigenous artist. The project anticipated diving deep into Indigenous culture and the proposition of an architectural response that prioritizes harmony and balance between nature and the built environment, between Indigenous traditions and a contemporary lifestyle.

3.2.2 MArch Design Studio II: Architecture and future of cities

This course is an introduction to architecture as an artistic and scientific endeavour, as well as an examination of its purpose and intentions, its processes, and its products. Students developed an understanding of the social, cultural, historical, technological, economic, and natural context influencing the design of buildings and other human-made objects and environments. A range of guest lecturers and different types of assignments exposed the students to a wide variety of perspectives and practices, while offering an opportunity to explore basic design ideas and activities.

3.2.3 MLA Landscape Architecture Studio II

This studio sought to improve the students' design skills and abilities through an investigation into a topical, issue-based problem, and the development of a solution in a landscape context. The course was divided into four broad topic areas including landscape identity (i.e. what makes a landscape unique); master planning and concept design (i.e. definition of objectives, strategies, and design concepts through which the landscape's identity can be preserved, revealed, or enhanced); design development; and design synthesis and communication. A key objective of the project was to develop a profound understanding about traditional Indigenous knowledge and practices. This process was guided by Indigenous Knowledge Keepers, the traditional stewards of the land.

3.2.4 MArch Senior Research Studio in Architecture. Nookóówayi (my home). An architectural design studio: exploring the future of housing in the Siksika Nation of Alberta.

This senior research architectural design studio explored the design of culturally appropriate housing options for the Siksika Nation of Southern Alberta. In this studio, students identified the priorities and sensitivities of the community and evaluate culturally appropriate design strategies that could help improve the status-quo of aboriginal housing by promoting pride, self-determination, and a sense of ownership. In this regard, the project considered the role of community participation in the design and construction of houses, as well as Traditional Ecological Knowledge or TEK, understood as the broad and interrelated knowledge, wisdom, and practices of Aboriginal cultures. The goal was not to produce generic affordable housing options, but specific solutions firmly anchored on local values, traditions, needs, and sensitivities. The studio also evaluated the potential of emerging construction technologies and materials such as digital design and prefabrication, 3d printing, modular architecture, as well as environmentally friendly systems such as solar energy capturing processes. Emphasis was placed on the ability of these systems to contribute to improved health and safety, durability, and the reduction of operational and maintenance costs. This course stands as the final design studio in the Master of Architecture program and therefore is crafted to allow students to demonstrate their competency and ability to balance complex design priorities such as culture, site, program, and materiality, in a comprehensive and meaningful way.



Figure 3: Student Design of a Clan Compound in Siksika Nation. Source: (Wilson, 2023)

3.2.5 MPlan history of urban planning

This course introduced the planning discipline and located it in a broader cultural context. The course approached planning history and theory from various angles including historically, by topic, academically, profession and location-based. Planning as a discipline is in the making -- its transformation since its formal institutionalization in the late 19th century is ongoing today. A portion of the course is dedicated to the discussion about decolonizing the disciplines history in the Canadian context. Why are we planning? The course provided a theoretical framework for discussion and practice. Students explored and evaluated the different theories, models, perspectives, technologies, forces and cultures that have and continue to shape the discipline. What does it mean to be a planner? The program was designed to address a range of aspects from modernist planning to economic, environmental, political and social planning aspects of occupying the land. Where does planning need to go? This course provided a foundation for students to understand the theoretical and ethical frameworks and to recognize the drivers behind the wider-ranging and multitude of roles for planners today. The starting point was the understanding that planning is a culturally defined role that operates at the dialectic intersection of society and space. As such, the course aimed to elaborate on precisely those responsibilities that come with such a position. Is there space beyond planning?

4.0. FINDINGS

> Elders describe holistic life as necessarily encompassing physical, emotional, intellectual and spiritual aspects. This can be portrayed in the form of a Medicine Wheel. More often than not, we find ourselves out of balance in one of these areas. Being deficient or out of balance spiritually will influence the other aspects of life. – (Stonechild 2016)

The teaching engagement workshops, and associated reflections, allowed for unique insights into where design education is falling short with regards to Indigenous ways of knowing and being in the world. Design education remains held to a Westernized standard, a process of knowledge transfer that commonly excludes other ways of knowing and seeing, thereby leaving valuable insights unrecognized. This is evidenced in the interviews with participating instructors: Vlad, Fabian, Mary-Ellen and Nooshin who each noted that Indigenous knowledge is more

embodied and experiential, conducted from a position of equity, and thus inclusive and conversational rather than overly intellectual and assertively hierarchical.

Indigenous ways of knowing can inform design education as it begins a shift towards a more equitable, diverse, inclusive and accessible future. The learnings discovered from this unconventional project range from complex relational observations encoded in what we know today as ‘academia’, to more easily implemented shifts in the pedagogical approach at a class-by-class level. In Non-Indigenous education, decision-making is typically centralized and influenced by administrative priorities and curricular standards. Indigenous projects, conversely, require the active participation and input of the community, Elders, and Knowledge Keepers, so that their collective priorities, needs, and sensitivities are identified and addressed from the beginning.

The strict and compressed timelines of Non-Indigenous education do not typically allow for genuine human connections to form or for deeply inclusive learning to take place. This is because Western approaches are anchored in a culture of immediacy and the relentless fragmentation of time. In non-Indigenous institutions, objectives are expected to be reached as quickly as possible, making it extremely challenging to engage in a meaningful way. If we can’t engage from a position of vulnerability, understanding and empathy, where listening leads to action, we run the risk of performative reconciliation in the form of public relations rather than doing the work (interview with Volodymyr Amiot). As expressed by several participating instructors: reconciliation and building trust takes time, we need to meet each other where we are at and not impose our ways of being onto those most often left out of the academic process.

An unexpected discovery that came up in interviews with instructors was that for international students, the history of colonization in Canada was a particularly challenging topic. While domestic students may have some exposure to these pressing matters, international students often lack such context. Most of them were previously unaware of the history of colonization in Canada. Professor Enrica Dall’Ara also emphasized the absence of a dedicated course on Indigeneity and culture within the school, creating a knowledge gap among both domestic and international students. Providing context about colonization becomes imperative to address questions regarding reconciliation. Bridging this gap involves addressing issues of insensitivity, intolerance, injustice, and discrimination in all environmental design practices. Understanding the unique challenges faced by Indigenous communities requires a comprehensive educational approach. Despite this deficiency, the research project was deemed to be effective in meaningfully embracing and incorporating Indigenous Ways of Knowing into studios, course, classrooms and school culture.

In his interview, Planning Professor Fabian Neuhaus noted that in design education, teaching and learning practices direct students to sample and imitate what they learn and see in the world, then implement that in their design work. Almost exclusively, what is seen and experienced in the built environment has been produced through a non-Indigenous lens. To teach only what is deemed of merit from a Westernized perspective, is to enforce the erasure of alternate ways of being in the world, including but not limited to Indigenous ways of knowing. This is an essential discovery to begin to digest. It is also one of the findings that can be acted on most quickly, by introducing students to more inclusive precedents by Indigenous designers. At the onset, this may be challenging for instructors who may not have knowledge of projects completed by Indigenous designers that are related to student projects. A recommendation here would be to broaden the scope of "projects” to be deemed as precedents by negating the necessity for projects to have a certain level of ‘professionalism’. This may be necessary due to the decades of institutionalized racism towards biracial, interracial, and people of colour within academic institutions, which almost exclusively, through barriers to inclusion, prevented them from becoming professionals in their respective fields. By this it is meant that perhaps the body of work generated solely from professionals exiting the academy is not in fact a broad enough, nor inclusive means of understanding the comprehensive body of work realized by Indigenous peoples in the landscape, planning or architecture realms.

In Walking Backwards Into The Future: Indigenous Wisdom Within Design Education, Nan O’Sullivan speaks to the need for integrating alternative modes of practice to stem the tide of human and environmental destruction, consumption, poor health and extinction (2018). Particularly potent in addressing the wicked environmental problems society faces today are indigenous ways of being with the land which require a reframing of neocolonial mindsets around land management and ownership:

> We need to step out of existing institutional and epistemic boundaries if we truly want to envision the worlds and practices capable of bringing about the significant transformations seen as needed (Escobar 2016, introduction).

It is a necessity to consider Indigenous perspectives in environmental design education. The ethos of environmental design has close ties to politics, westernized land management and capital interests, all of which can interfere with a genuine connection to the land (Mary-Ellen Tyler April 2023) make it particularly influential in shaping the world, and society at large. The teacher involved in this particular project, within our research initiative, insisted on the benefits of collaborative approaches, co-creation of knowledge, and responsible land management that looks seven generations into the future, as methods we can adopt from indigenous practices. Working towards the decolonization of the design process and thus design culture, the folding in of Indigenous design methodologies embraces a future of co-design where the boundaries of Westernized institutional methodologies are negligible. The importance of understanding reconciliation, embracing creativity, and acknowledging the interconnectedness of all things is paramount for environmental design to continue contributing meaningfully and positively to the future.

The hiring of Indigenous Knowledge Keepers to help guide the reconciliation process was something that each instructor highlighted as a need for moving forward. Access to more Elders, Knowledge Keepers, and Indigenous community members who live and work in this realm can be challenging -- local FNMI groups can lack trust that formal institutions can be equitable and not extractive. This fear could be mitigated by ensuring that the community

“be the main beneficiary of the project" (Reitsma et al. 2019). To ensure this, one recommendation was to help develop relationships and build trust by finding people who "walk in both worlds” (Mary-Ellen Tyler April 2023), meaning that they are both indigenous and working within, or adjacent to the profession or have established relationships with professors. These people who are a part of both design culture and Indigenous culture can make bridging the gaps a much more streamlined process by acting as an intermediary during consultations. They have connections to the community and can identify key contacts to seek out, as well as advise, researchers and teachers concerning relationship building. These people, facilitating vital relationships, could be staff, students or outside contacts. Here it becomes clear that hiring more Indigenous staff, attracting more Indigenous students and inviting more Indigenous reviewers and experts into the classrooms to provide feedback on student work, would play an integral role in building trust, respect and relations. Through this process, students would be exposed to Indigenous ways of interpreting the world on a more frequent basis, which was a suggestion made by both Professor Enrica Dall’Ara and Fabian Neuhaus to increase acceptance, empathy and understanding.

A part of Indigenous ways of knowing includes a ‘pedagogy of experience’ – that is, if students and professors had access to immersive experiences throughout their education at the Architecture, Planning and Landscape school, not only would the degree programs integrate methods of Indigenous knowledge transference in practice, but in addition to this, participants would be able to develop relationships with the communities hosting the events. Though Western institutions approach environmental design education in more rationalistic and theoretical ways, incorporating experiential knowledge can inform and enrich designs through a more tactile, immersive and intersectional way.

By bridging the gap between indigenous ways of knowing and design education, the academy places value upon multiple modes of knowledge transfer and ways of being in our world. It acknowledges that Westernized ways of teaching and learning are not holistic and that there is much more to learn from other, previously disregarded perspectives. The authors contend that Western institutions could benefit from the integration of Indigenous ways of knowing, especially as there are distinct needs for, and growing interest in, attracting more Indigenous and biracial, interracial, and people of colour to the institution. This inclusion of other ways of knowing signifies an encouraging shift in academia's approach to education, as well as an acknowledgement of its historical merits and faults. Together, by bridging the gap, design education and Indigenous perspectives can begin to collaboratively and collectively build a future in which post-secondary education is rendered as more inclusive, accessible, equitable and diverse.

5.0 NEXT STEPS

> If knowledge stays hidden, it will do no good. It will only do good once it is shared. (Casey Eagle Speaker. Bridging Cultures Workshop 2022)

Professors at the School of Architecture, Planning, and Landscape indicated through exit interviews that the path forward is not singular. Rather, it necessitates ample time and a pronged approach. Understanding that reconciliation is a process that requires patience, persistence and well-intended efforts, we can begin to imagine a future in which Indigenous world views are incorporated into design education at both graduate and undergraduate levels.

Naturally, to design from a position of empathy and understanding of alternate ways of knowing creates the opportunity to manifest work that is both unique and speaks to other modes of being in the world. This road starts with relationship building. It is necessary to develop authentic relationships and build trust over time with community members in the local nations. Innate in the development of relationships is the building of trust, which then furthers the integration and bridging between Indigenous ways of knowing and design education.

As these modes of practice and relationships are developed, immediate action can be taken to create an Indigenous- collection of stories, that are open and accessible to all. This collection of lessons and teachings was noted as a necessary next step in numerous interviews within out research, and was identified as a beneficial resource for course building and student development moving ahead.

Building off a resource collection, a library of Indigenous teachings, projects, contacts, and precedents in each field of study, would undoubtedly assist professors as they prepare to integrate more Indigenous ways of knowing and seeing into their course content and delivery.

We believe that bridging cultures, Indigenous Culture + Design Culture, is essential to innovation, growth and development in SAPL as today becomes tomorrow. Further, the proposed pedagogical recommendations and reform will inform and inspire our steps as SAPL builds knowledge, heightens performance, shapes profile and raises reputation as a leader in integrating Indigeneity and design in higher education.

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The Role of International Experiences in Architectural Education: Research Reflections from Thailand

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ABSTRACT: In an era defined by unprecedented connectivity and cultural exchange, the role of international travel in shaping architectural pedagogy stands as an unequivocal cornerstone of transformative learning. This autoethnographic paper offers a unique perspective on the impact of self-directed and student-led international research experiences on the mind of the young designer. This paper describes the outcomes of two distinct international student-research experiences in Thailand during the Summer of 2023.

As national identities become blurred and architectural challenges become increasingly global in scope, students desire an enriching curriculum that addresses diverse built environments, traditions, and perspectives. International travel provides a unique opportunity for the next generation of designers to grow academically, professionally, and personally.

In the summer of 2023, two architecture students from the same university embarked on separate research experiences in Thailand. Graduate student, Elijah, explored vernacular masonry construction methods, building upon his work in a previous design studio focused on masonry construction and rural housing in tropical climates. The observational method of research allowed for a connection with Thai people and culture that helped inform their architectural conventions. Undergraduate student, Amelia, worked on an interdisciplinary team funded by the National Science Foundation to study agricultural land use change in Eastern Thailand using remote sensing techniques.

By engaging in international research, these profound experiences transcend the confines of the classroom enhancing student skills of adaptability, cross-cultural fluency, and a deep understanding of the nuanced aspects of different cultures. This underscores the significance of international travel, which is not just important but *essential* for the advancement of future architects and designers. The field of architectural pedagogy serves as a foundational platform through which the integration of international research can elevate the skills and perspectives of young designers, preparing them for a future grounded in global engagement.

KEYWORDS: international, independent, research, pedagogy, student-led

INTRODUCTION

As architecture is continuously defined and refined through culture and learning, the need for continued connection with other cultures and people will grow. Architects must look towards a global perspective. As populations rise to new limits and the urban landscape explodes, levels of pollution increase and easily available resources decrease (Forman and Wu, 2016). Thus, architects and urban planners are needed to create an urban landscape that can withstand the growth and perpetuate informed practices in design. In response to this shift, architecture pedagogy must accommodate these incoming demands for the architects of the future. By being globally informed designers, students will be better equipped to accommodate the rapidly changing world. This is managed through educating the young designers of global perspectives through active participation and hands-on learning. International research provides a platform for this, allowing students to better understand people who live in differing cultures and hold a different set of needs, which builds a foundation of architects that will be able to create a new urban landscape that fulfills the needs of the ever-growing populations. There is a need for new expertise to conform to the evolving landscape. One of well-informed designers who understand ecology, landscape, water, transportation needs, infrastructure, and community (Forman and Wu, 2016).

In the dynamic realm of architectural education, the quest for innovation transcends borders, beckoning educators and scholars to traverse international landscapes in search of transformative insights. As the architectural pedagogy landscape evolves, this paper embarks on an exploration of student-led international research, unraveling the potential for cross-cultural influences to shape the future of architectural education. In the midst of diverse perspectives, methodologies, and environments, we pursue intersections where global collaboration and localized wisdom converge.

1.0 BACKGROUND

Architectural pedagogy includes meaningful dialogue about international architecture often just in a classroom setting. As national identities become blurred and architectural challenges become increasingly global in scope, it is clear that architectural education should evolve as well. To create true global citizens, students require an enriching curriculum that critically explores diverse built environments, traditions, and perspectives. International travel provides a unique opportunity for the next generation of designers to engage in this type of discourse as well as grow academically, professionally, and personally. The field of architecture serves as a foundational platform through which the integration of international research can elevate the skills and perspectives of young designers, preparing them for a future grounded in global engagement. By engaging in international research, these profound experiences transcend the confines of the classroom enhancing student skills of adaptability, cross-cultural fluency, and a deep understanding of the nuanced aspects of different cultures.

Study Abroad programs offer a unique experiential understanding of pedagogical approaches to learning. By immersing students in a country foreign to their own experience, there are often moments of intense growth educationally and personally, especially when looking at it from an architecturally pedagogical perspective (Lyle 2011). Oftentimes there are unique perspectives within the visited country that challenge conventions. This allows them to synthesize their knowledge base and offer contributions they feel are helpful as ways to challenge their assumptions (Macedo 2017). The goal of a study abroad is to continue an educational path in a new place. During their college years, students' travel patterns and preferences begin to take shape. Mody et al.(2017) found that those who accumulate a greater number of travel experiences during this period tend to develop a strong desire for more travel experiences. Additionally, they exhibit a willingness to be more venturesome in their travel behaviors, pushing themselves to be more open to new cultures and ideas (Mody et al. 2017). This travel-inspired level of learning help push the narrative that travel is imperative to supplement education. By encouraging people to understand themselves further and push beyond moments of discomfort allows students to learn. Architecture pedagogy finds itself often teaching about culture and history in a classroom setting that is far removed from the ‘place’ it is exploring. The concepts within architecture pedagogy persistently center around learning as a form of work, where the sparks of creativity come from ideas of play. (Roquette et al. 2022) By traveling, and experiencing a sense of ‘play’ through intrinsic research pursuits, students have opportunities to learn differently than they did previously.

2.0 STUDENT RESEARCH GOALS

This paper describes the experiences and outcomes of two students who engaged in distinct student-led international research programs in Thailand during the summer of 2023. Inspired by autoethnographic literature, student observations are recorded both as documentary and narrative accounts. In this case, the paper offers reflections of students' personal journeys and academic discoveries during their research endeavors in Thailand.

In summer of 2023 fourth-year undergraduate student, Amelia, participated in a National Science Foundation sponsored *International Research Experiences for Students (IRES) p*rogram titled *Consequences of the COVID-19 Pandemic on Landscape Change in Tropical Crop Cultivation (National Science Foundation Grant No. 2153579)*. Amelia was part of a diverse team consisting of one graduate student and five undergraduates with varied backgrounds, representing departments such as geography, urban planning, sociology, environmental science, and architecture. The team's interdisciplinary composition brought together a wide range of skills and perspectives. Collectively, the team sought to explore how crop cultivation in Eastern Thailand changed between the years of 2017-2023 due to the economic, social, and political effects of COVID-19? Specifically, research questions included:

1. Which crops have changed and in which locations?
2. Which crops have seen rapid increase in production?
3. Which crops are shrinking in production?

During their time abroad, the students utilized remote sensing techniques and a machine learning model in Google Earth Engine to map crop changes in the Eastern Region of Thailand. The program spanned five weeks and was primarily based in Bangkok, with approximately half of the duration dedicated to collecting samples in rural areas. In the evenings and weekends, students were encouraged to participate in cultural activities and pursue their personal interests. What were the project outcomes?

In the same year, Graduate student, Elijah, participated in an independent travel fellowship sponsored by the local American Institute of Architects chapter. This fellowship offered an opportunity to study architecture in a place of their choosing. Elijah, already interested in vernacular brick construction techniques in rural settings, found a rich heritage of brick construction in Thailand. Using qualitative research methods that “locate the observer in the world”, Elijah conducted field notes, informal interviews, conversations, and photographs to create a set of “interpretive, material practices that make the world visible” and “turn the world visible” (Denzin and Lincoln, 2018,43)

As a way to narrow down the broad topic of international architecture research the graduate student composed questions to focus the research. Research questions included:

1. What means and methods are used for housing construction in rural Thailand?
2. How is masonry used in this climate and cultural context?

These questions fueled the travel and conversations with local architects and builders. Much of the research was conducted through visual means, i.e. photographs, sketches, and observation. This collection of documents and artifacts, as well as notes concluding each day's events, were synthesized at the end of the travel experience to be further analyzed. Having stayed with a host family in Bangkok, Elijah was able to communicate effectively with locals about their homes and construction methods. The research took place in Bangkok, Chiang Mai, Pai, and the surrounding rural villages and towns. These days of Travel were essential for observations, and understanding cultural norms. The student researchers did their research over separate times within the country with only one day of overlap when they met in Bangkok. (Figure 1)

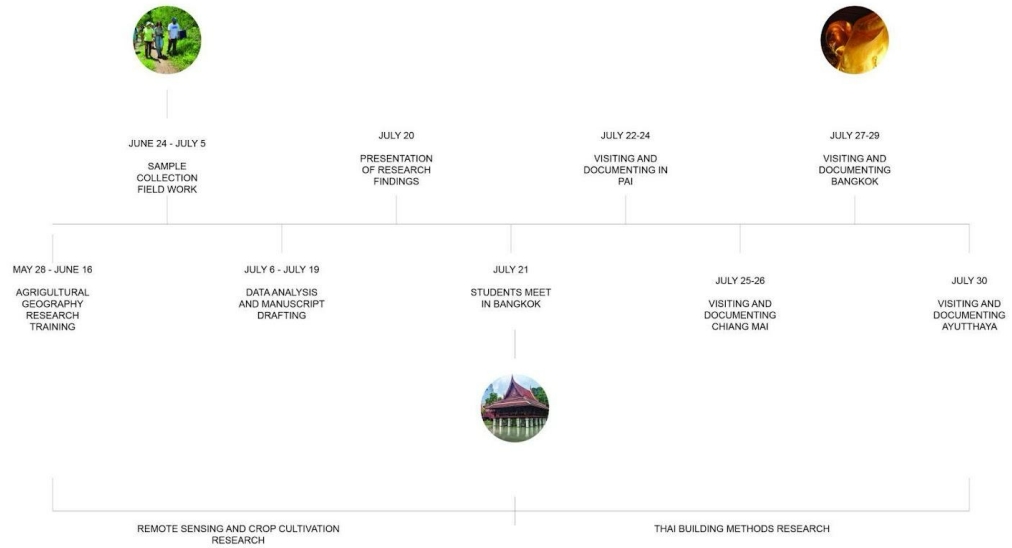


Figure 1: Timeline of students' research in Thailand. Source: (Todd 2024)

3.0 STUDENT OBSERVATIONS

This section will describe the observations and cultural encounters that allowed for introspection and student development. These observations are summarized in three primary categories that can support multi-cultural architectural pedagogy: 1) embracing discomfort, 2) respect for nature, 3) cultural Embodiment in Architectural Design.

3.1 Embracing discomfort

Discomfort is a natural part of growth and development. The discomfort of being in a new place pushes one to challenge their sense of contentment, urging them out of their comfort zones and into uncharted territories. This forces a person to be adventurous and engage with others for assistance and guidance. By reaching out and seeking help, they not only build essential social skills but also become more resilient and confident in navigating new avenues in their life. Through travel, individuals encounter vastly different cultural phenomena that challenge their own systemic social structures and norms. Exposure to these diverse cultures fosters a deeper understanding and appreciation for the uniqueness of others, cultivating a broader perspective and a greater tolerance for cultural differences. This cultural immersion can be eye-opening, revealing the richness and complexity of the world beyond one's familiar surroundings.

The geographic and cultural landscapes of Thailand are the result of a unique blend of external influences and indigenous traditions. Navigating the country alongside locals and studying its architecture and geography provide valuable insights into the cultural development and sense of place within the country. Yet, these insights are often brought about by personal and interpersonal discomfort. Rebecca McLaughlan and Stephanie Liddicoat argue in their 2017 paper that there are two ways a “pedagogy of discomfort”, a term coined by Megan Boler in 1999, can be implemented in the architectural education: (1) by disrupting the student’s way of seeing, and (2) by disrupting the way of making (McLaughlan & Liddicoat 2017). Experiencing new ways of life can cause discomfort, even in the simplest of tasks, inherently disrupting the student’s way of seeing. When the mundane becomes exciting, confusing, or frightening, the observer is forced to consider their own perceptions and norms in a society differing from their own. By embracing the discomfort implicit with being an obvious outsider, students were able to experience Thailand's unique character by understanding their own biases and cultural assumptions. (Wooley and Ayelet)

When discussing cultural discomfort in Thailand, it is important to note the tremendous variety of environments within the country. Bangkok, specifically, is a chaotic and complex urban environment. For many, who have spent their lives in smaller cities or more rural areas, the density itself may evoke a sense of discomfort. Though it was once navigated almost exclusively by boat, roads, and increasingly, rail lines dominate the city today. Navigating the city by foot requires a sense of boldness and confidence. Furthermore, Bangkok is home to a variety of cultures,

languages, and religions, which provides a rich environment for learning and exposure. Despite the appearance of chaos, Bangkok is vibrant and unpredictable, and yet, systematic.

Markets, for example, can be difficult to navigate. They constantly have changing vendors and product variety. They are open only on certain days of the week and may only last in that location for a short period, depending on spatial availability. Though on the surface level it may not appear this way, the ever-changing nature of the Bangkok market is often rational. Markets adapt vendors and variety to the available seasonal product. They open on the days that may receive the most customers, and they close for inclement weather. In this way, the market is regulated by systems of nature, the habits of its people, and the cultural need for flexibility. The market venue typology provides a unique set of lessons for the architecture student.



Figure 2: Truck bed full of salak, ready to be taken to the market. Source: (Todd 2023)

As international visitors to a country unfamiliar, a sense of discomfort is sure to arise. The language barrier, regardless of social adaptability, emphasizes one's foreign status in society. Being thrust into a challenging, unfamiliar environment forces student travelers to adapt and embrace discomfort. Oftentimes, by confronting and embracing the discomfort that comes with travel, students develop a thirst for new experiences. This initial leap into the unknown can spark a lifelong passion for exploration and discovery. As they continue to seek out new travel experiences throughout their lives, they grow into lifelong travelers and well-rounded individuals, enriched by the diversity and knowledge gained from their journeys.

3.2 Respect for nature

From experiences in Western culture, there is often a reverence for the natural world yet often people lack an understanding of what it takes to coexist and understand their place in the natural world as a whole. Historically, in the United States, there is an anthropocentric view of nature, or in a sense of human domination toward nature instead of fostering a sense of oneness with the surrounding land. (Marx) Instead, the students observed that respect for nature, buildings, religion, land, and people rank high in the social norms in Thailand. Oftentimes, out of respect for the spirits that occupy the land, small houses called "spirit houses" are placed on the property so that people may live in communion with the spirits. By feeding them with offerings of food, drinks, and trinkets, these spirits look after the house and the land. Respecting the spirits is often a priority in some households. This ritual of spirituality connects the person to the land, grounding them, and engaging them into a deeper understanding of self regarding the world.

As Amelia's research team moved to more rural areas, it was noticed that there was a persistence of this sort of adaptable lifestyle. In speaking with local farmers she learned that many of them select their crops based on a multitude of factors, including market value, weather conditions, labor intensiveness, and soil type. As these factors change year to year, the farmers adjust to provide for themselves. The COVID-19 Pandemic provided a unique opportunity to study this. Pandemic policy, climate change, and economic demands affected farmers and their crop choices, leading to major shifts in crop selection. This volatility of the Eastern Thailand agricultural landscape is a means of resilience. Smallholder farms stay afloat by being flexible to the environmental and social needs of their locations. According to Amelia,

> I was struck by this impermanence. The impermanence of the city and the impermanence of the land. Though the city and the agricultural areas are sacred in their own right, this sacredness accepts and even appreciates change. By choice or necessity, the built environment is not idle. (Todd 2023)

As this country resides in a tropical climate zone, seeking ways to move the hot and humid air through the spaces is vital for people. Most houses contained passive cooling solutions. The use of tall ceilings with vents to displace the hot air. The roof systems have large overhangs to prevent the solar heat gain from entering the living and sleeping spaces. Dealing with the humidity and heat leads to buildings with light materials. Teak wood being a traditional building material is still often used, though harvesting teak is illegal in Thailand many houses are made from pieces of old houses. Many, though, are living in houses that have been around for decades. These homes have additions built from brick and concrete creating a mixed vernacular house. Though there was a desire to find a rural housing typology that was created purely from masonry, it was clear that masonry was not used as much historically for rural homes. This was not totally fruitless as many of Thailand's ancient temple structures were built from brick and plaster. Thailand has an incredible connection to nature through its religious beliefs. According to the Thai Public Relations Department of the government, 93.5% of the population is Buddhist (Thailand Public Relations Department 2022). The religious spiritualism connects people to the world directly around them bringing a sense of mindfulness into their actions as well as how nature is revered. This reverence to nature, especially in poorer rural regions, is shown through their built environment, for example, houses are designed to mitigate flood waters during the rainy seasons by being placed on stilts. These design choices are often centuries-old practices rooted in survival techniques. Understanding how the natural world can impact a region can help develop better building practices. By building with intentions to complement and not dominate the natural setting create a harmony between the human-made and Natural world.

3.3 Cultural embodiment in architectural design

Despite diverse climates and cultures across the United States we often see similar built typologies across the country, Thai architecture is a testament to the enduring legacy of cultural traditions, reflecting a unique blend of history, art, and heritage. The architectural tapestry in Thailand serves as a reminder of the significance of cultural roots, adding depth and meaning to the built environment in ways that differ from the more contemporary and often contextually independent developments happening in many American cities. There are Buddhist temples all over Thailand that have been built over many decades and centuries. While the more recently built temple structures employ contemporary construction techniques, many of the old temples use bricks and plaster for their construction. The Ancient City of Ayutthaya is built from bricks of differing sizes stacked in the general pattern of the object. This technique was seen in the walls, statues, and temple structures. This technique of bricklaying and plastering over the brick (figure 2) was also seen at a wealthy family's house that turned into a museum in the city of Chiang Mai. This house, although not rural, carried a lot of the same properties as other houses built around Thailand. The open-air ground floor space built out of the brick and plaster technique holds a firm foundation. Then teak wood is used for the residential second level. Teak was also used for the kitchen building that resided on that same land. Teak was used for its breathability in the hot, humid tropical climate. The movement of the air to keep people cool was important. High ceilings and roofs with vents allow for this air movement. It is clear that brick was used and has been used in Thai construction, however, the built environment it was used was mostly for wealthy patrons or religious architecture. Though it seems that the housing that used bricks in rural areas was rare, brick masonry has a deep history in Thailand's built environment.



Figure 3: Masonry wall built from clay brick with white and red plaster on the exterior faces. Source: (Rutkowski 2023)

Thailand's rich architectural heritage, which is deeply rooted in cultural traditions, offers valuable insights for architectural pedagogy and underscores the importance of embracing cultural roots in the built environment. The importance of traditional techniques, such as the use of bricks and plaster in [the example above…] can add depth

and meaning to contemporary architectural practices. Additionally, the emphasis on passive strategies provides a lesson for sustainable design in the context of energy consumption and climate change. By studying and appreciating these diverse building styles firsthand, students can draw inspiration to create spaces that resonate with cultural significance, promote sustainability, and promote a deeper connection between people and the built environment.

4.0 PERSONAL AND PROFESSIONAL DEVELOPMENT

As the students delved into distinct subjects within the same country, they not only expanded their understanding of the culture but also gained insights into their own research methodologies. This transformative encounter not only underscored the significance of travel and research in strengthening educational foundation but also illuminated the impact these experiences had on both professional development and personal growth. Delving into distinct research projects across an international landscape afforded an unparalleled opportunity to surpass the confines of our academic cushion and immerse in the vibrant tapestry of another culture.

As they navigated through unfamiliar contexts and engaged with diverse architectural paradigms, their understanding of architecture and its relationship to the environment deepened immeasurably. The exposure to different cultural frameworks challenged preconceptions, fostering a nuanced understanding of the intricate relationship between built environments and societal dynamics. This newfound insight not only enriched them architecturally but also broadened their intellectual horizons, positioning them as architects equipped with a global perspective. The challenges inherent in navigating foreign territories, both culturally and academically, nurtured resilience, adaptability, and an acute awareness of the interconnectedness of the world. These qualities, integral to thriving in the ever-evolving field of architecture, transcend the confines of academia, permeating into every facet of our personal and professional lives.

The experiences of being an international researcher develop growth professionally as well as personally. This holds precedent in the arts with what was known as the Grand Tour. Jean Sorabella, Art historian and writer for the Metropolitan Museum of Arts explains, oftentimes where, starting in the sixteenth century, people who had the means would travel internationally as the culmination of their education. (Sorbella 1) Their learning of the world around them as well as their developing skills helped them professionally. Architects and artists would travel to Rome to learn from antiquity, bringing back skills of design that would help their work in their home countries. This type of knowledge and growth that people experienced during the Grand Tour is parallel to the learning and rigorous analysis that helped them learn skills to bring back to the profession.

During their travels, personal development played a vital role in our research. By being in Thailand, surrounded by people, differing cultural norms, and ancient and new architecture, we began to adapt to the country. When conducting our separate research, however, there was even more growth by understanding how people interacted with each other, and to their settings. This research led Elijah to engage with local builders and architects to understand their built environment. This development helped facilitate a working relationship between Elijah and a Thai Architect and Ph.D. candidate who played a role in challenging the conventions of architecture knowledge and personal biases. Personal growth is just that: very personal. Engaging with people of vastly different backgrounds forced them to question our norms and open up more to the world.

By embracing the transformative power of international research, they not only contributed to the cultivation of a new generation of architects endowed with greater wisdom but also fueled our own evolution as individuals. The fusion of diverse experiences became a catalyst for self-discovery, fostering a heightened sense of curiosity, empathy, and a lifelong commitment to the pursuit of knowledge. In essence, international research emerges not merely as a professional imperative but as an enriching journey that shapes the very fabric of our identities, laying the groundwork for a future where architects are not just creators of spaces but stewards of a globally informed, culturally sensitive built environment. Traveling to new places to research and understand architecture and building techniques builds a well-rounded education in building design. Lyle Culver, a PhD scholar from Florida International University interested in the influence of study abroad programs on students, both graduate and undergraduate, for their future endeavors. In the consequent interviews with these students, Culver found that “this was also the most important aspect of their education as architects because it heightened their interest in architecture.” (Culver 2011 This idea can be brought to other international experiences and research that is not just for architecture studio courses. Traveling to other countries allows one to learn about oneself from a different perspective. This new perspective pushes each person to develop skills they may never have had before traveling.

The experiences of being an international researcher develop growth professionally as well as personally. This holds precedent in the arts with what was known as the Grand Tour. Jean Sorabella, Art historian and writer for the Metropolitan Museum of Arts explains, oftentimes where, starting in the sixteenth century, people who had the means would travel internationally as the culmination of their education. (Sorbella 1) Their learning of the world around them as well as their developing skills helped them professionally. Architects and artists would travel to Rome to learn from antiquity, bringing back skills of design that would help their work in their home countries. This type of knowledge and growth that people experienced during the Grand Tour is parallel to the learning and rigorous analysis that helped them learn skills to bring back to the profession.

> Undergraduate Student Testimonial:
> This idea of ever-changing spatial environments quickly became relevant in my studies. Upon returning back to my home campus, my Fall studio was entitled “Buildings on Their Own Terms”. Programless

> buildings that could be used and reused by a variety of occupants, and for a variety of needs. I often thought about the ever-changing Thai market venue, and of the immediacy of response Thai farmers had to shifting conditions. How might buildings be constructed if they were intended to be in constant states of change? What constraints would we apply to still make them functional? (Todd 2023)
>
> Graduate Student Testimonial:
> By pursuing Thailand as the country whose architecture I wanted to study, there was a sense of exploration to learn from different cultures. Returning to campus after the trip allowed me to reflect on the trip and what I learned. By leaping headward into learning about rural Thai architecture, it sparked a fire into the direction of study I want to pursue. Exploring different cultures vernacular building techniques and architecture taps into how to study some of the other factors of international design and appropriate technologies. I learned how to view myself through an international lens to set my intentions and experiences to be diverse, open, and academic. (Rutkowski 2023)

In Thailand, our experiences were designed to grow academic and professional skills. Conducting both quantitative and qualitative research, we honed analysis and comprehension skills to resolve complex problems. The practical skills of resilience for research and the rigor of research will forever influence our design process, drawing from both tangible and intangible aspects. The growth experienced during our time in Thailand will serve as a foundation for ongoing success in future endeavors.

CONCLUSION

Student-led international research opportunities in architectural education offer invaluable lessons in research protocol, contextual design, architectural history, and cross-cultural fluency. Most importantly, it equips students with the tools necessary to solve the global issues facing our planet in a sensitive and multi-cultural way. As students engage with foreign cultures, their curiosity about architecture becomes greater (Culver). When students participate in the development of research protocol they think creatively and collaborate with others.

The experiences gained extend beyond the academic realm, shaping students into well-rounded individuals equipped with a global perspective. Moreover, participation in research empowers students to think innovatively and collaborate effectively, skills that make a good designer. By fostering a deep appreciation for cultural diversity and encouraging creative problem-solving, student-led international research lays the groundwork for a new generation of architects who are not only technically proficient but also socially and culturally aware.

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POSTERS

The Future Role of Travel in the Traditional Travel Studio: Lessons from the Pandemic

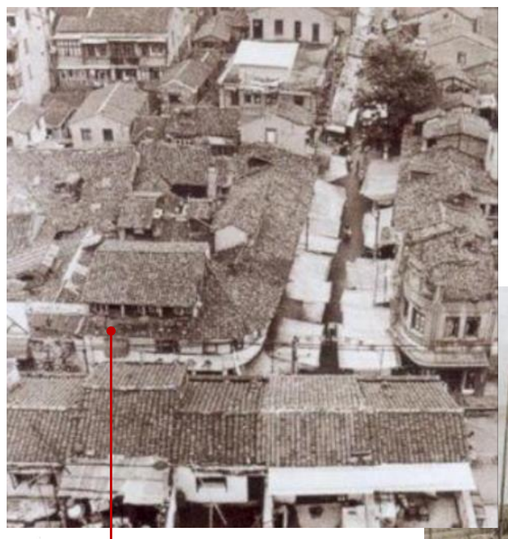
Camille Sherrod
Kean University, Union, USA

KEYWORDS: pedagogy, travel studio, post-pandemic teaching

ABSTRACT: How would the travel studio experience differ if it were no longer based on physical immersion?

Travel remains at the core of architectural education for many undergraduate and graduate degree programs. Pedagogy that mimics the cultural enrichment that results from immersion is needed to serve future generations of architectural students impacted by environmental shifts and unforeseen epidemics that limit mobility. However, not much has been publicly presented regarding the outputs and experiences teaching travel studios remotely. As an alternative to traditional travel studios that often result in limited participation and are not suitable for times of uncertainty, border restrictions, and financial insecurity, the objective of this work is to assess the effectiveness of remote teaching methods in imparting cultural enrichment comparable to traditional immersive travel studios. The methodology involves the collection and analysis of student design projects from two undergraduate and graduate travel studios impacted by the COVID-19 pandemic and associated travel restrictions in 2020-2023.

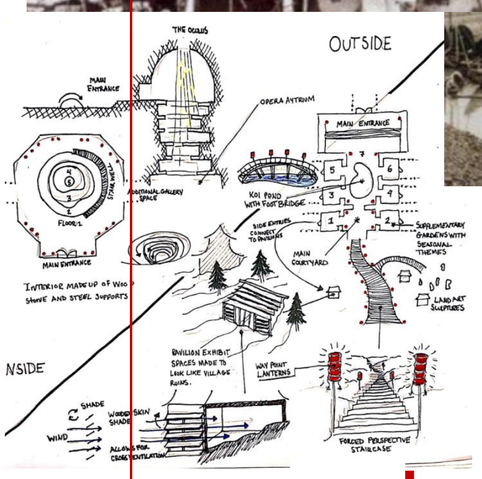
The goal is to reimagine the travel studio as one that aims to rediscover local communities from marginalized perspectives. Students devised strategies and innovative design solutions reflecting an understanding of culture and contributing to a retelling of notable heritage sites with conflicted histories. Outcomes highlight opportunities for 1) the use of cultural mediators from marginalized communities to substitute ethnographic research ensuring accurate representation, 2) embodied experiences through games to enhance cultural understanding, 3) entry points for immersive technology and 4) improved strategies to utilize cultural precedents. The design research shown here is a work in progress, aiming to develop a curricular model that substitutes in-person experiences without compromising quality. The showcased work demonstrates how design studios can participate in historical retelling as a value substitute for immersive travel.



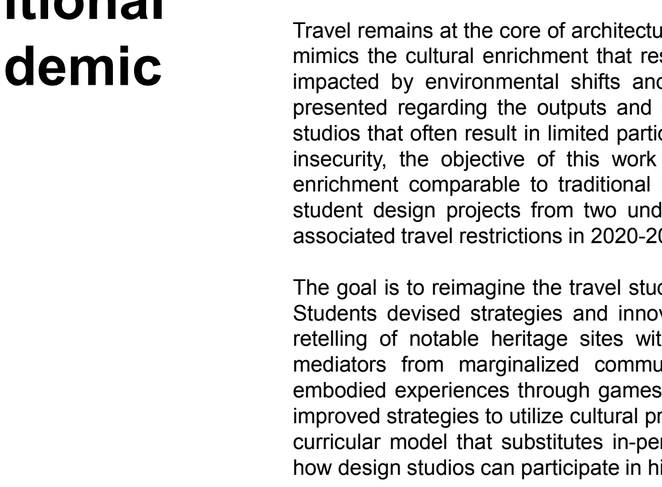


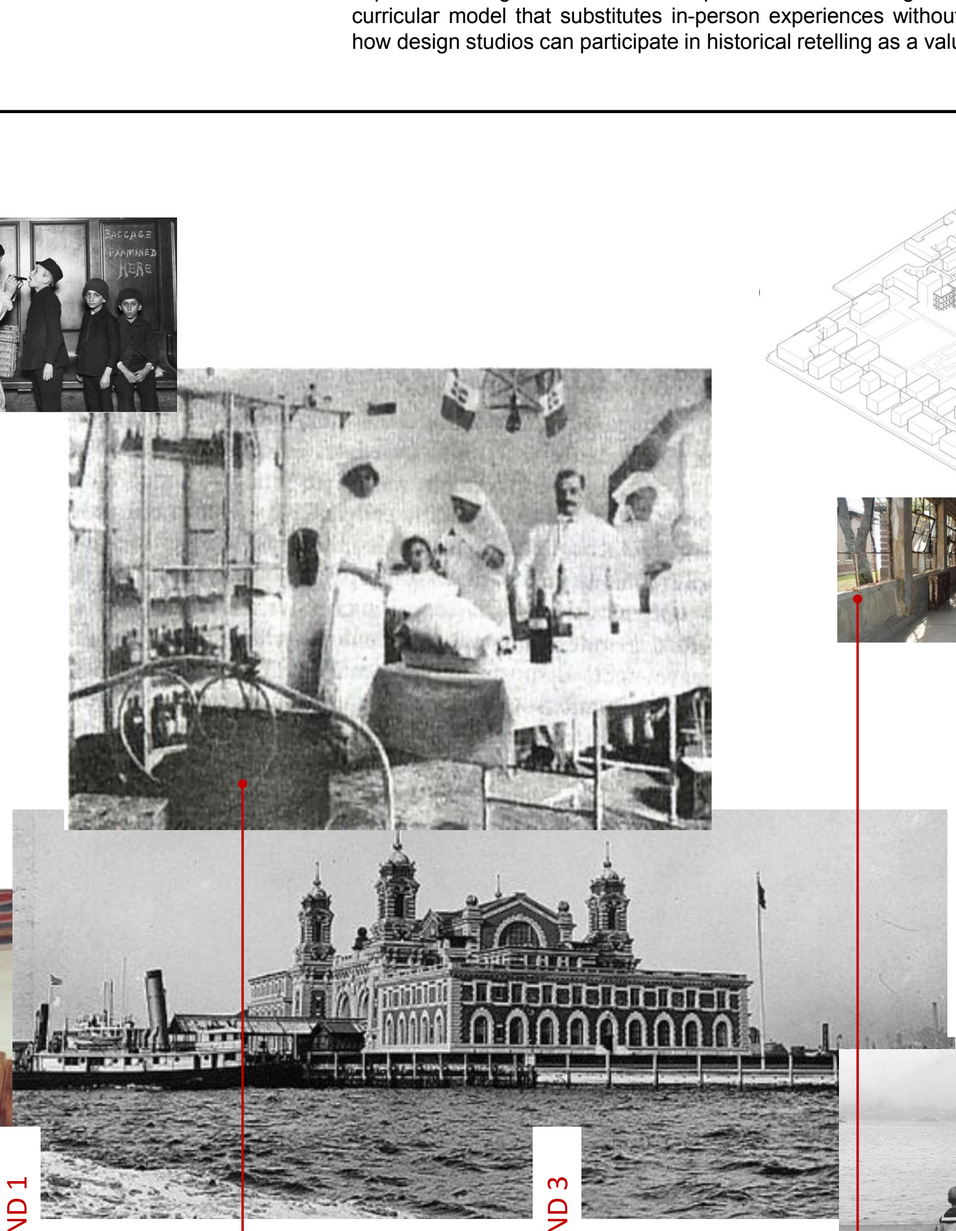


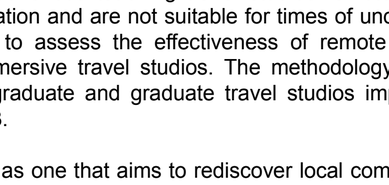
- It is then placed into a vat of water and the pulp is pressed onto a screen and left to dry in sheets of paper.

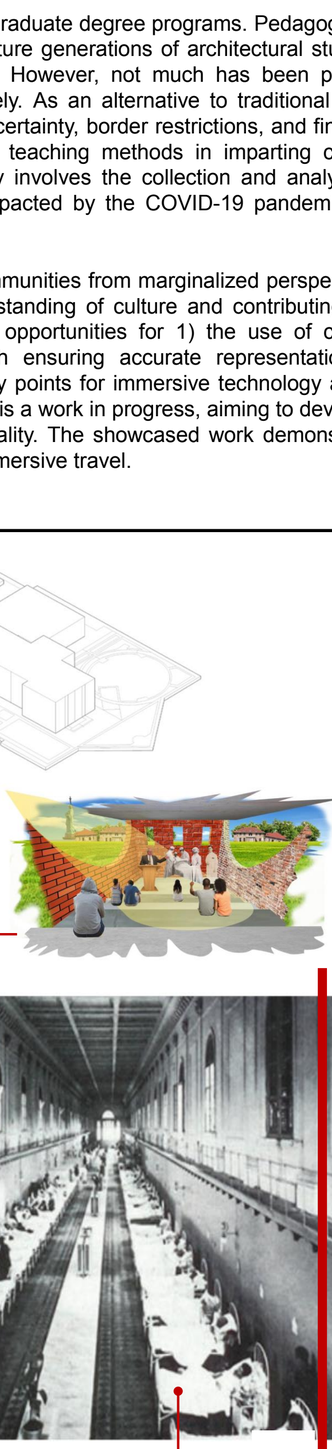


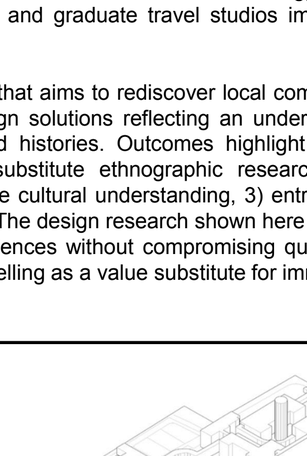














ZHEJIANG PROVINCE

GOU PU CENTER

JAMES BRETT

WENZHOU PAPER MILL

ELLIS ISLAND 1

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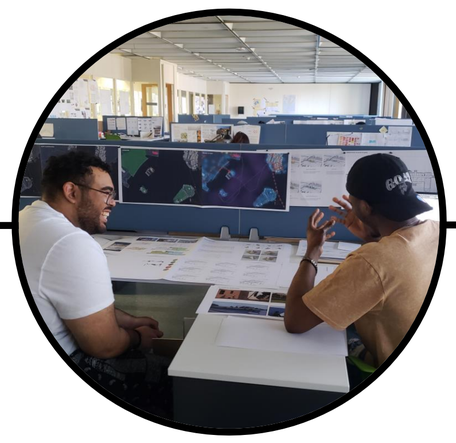
KACPER WILCZYNSKI

1368 | 1892 | 1900 | 1906 | 1954 | 2023

TRAVEL STUDIO LEARNING OBJECTIVES ACHIEVED THROUGH HISTORY, HERITAGE, NARRATIVE, AND CULTURE









DIGITAL ARCHIVES

Newspapers from the early 1910s describing the massive waves of immigration, the largest the US has ever seen

NATIONAL MUSEUM EXHIBITION

Guided site visit exploring artifacts and collection of passenger records in former processing station

INTERDISCIPLINARY PEER REVIEW

One-on-one peer reviews from the fields of environmental science and anthropology

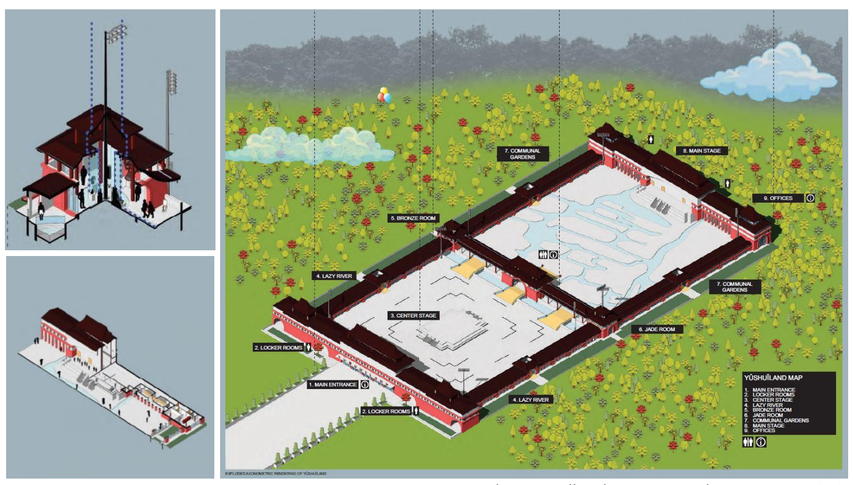
IMMERSIVE VIRTUAL ENVIRONMENT

Incorporation of campus-based virtual tools, critiques, and collaborative spaces

CULTURAL + ENVIORNMENTAL DESIGN STRATEGIES

"The cultural moments surrounding water are responsible, in part, to Wenzhou's status as a successful, prosperous coastal city. Inspired by traditional cultural attractions infused with the many cultures of water, YushuiLand is a contained ecology that utilizes passive building strategies to provide space for the local community."
Andrew Engelhardt, Kean-Wenzhou Campus, 2020

"Every facility on the island contains the memories and stories of past inhabitants who have traveled to Ellis Island seeking out a new beginning. Both radiant and somber, these memories include denial of citizenship to the US, resulting in a prolonged stay on the island. The space being designed inside the walls of the abandoned hospital aspires to display these stories in a way that places you in them."
Ryan Barbour, Kean-Union Campus, 2023



Andrew Engelhardt, Kean-Wenzhou Campus, 2020

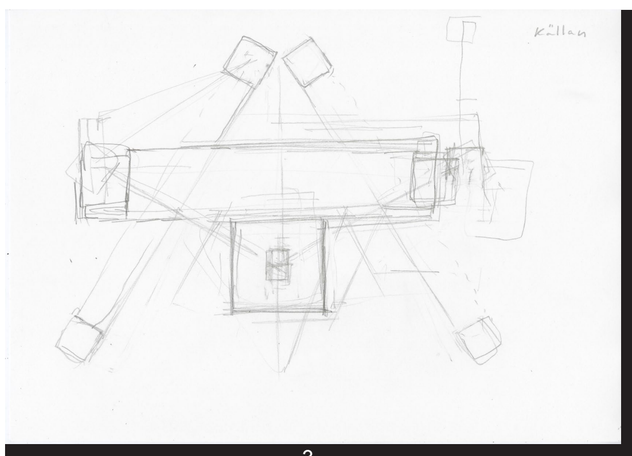


Ryan Barbour, Kean-Union Campus, 2023

PERFORMATIVE LEARNING IN THE FIELD OF ARCHITECTURE - TO AWAKE A DESIRE TO EXPLORE THE UNKNOWN

Björn Lundell, Jack Dalla Santa
Arkitekturskolan STHLM, Stockholm, Sweden

In our own practices we constantly develop various concepts and methods and use them as tools to generate architecture. It's a creative way, helping us to open up a responsive and resonant relationship to our work with architecture. We use concepts to activate senses, body and mind alternately in processes, searching for a vibrant and diverse architecture. As teachers we refer to Hartmut Rosa and his book Resonance. "Education in the sense of resonance theory, however, is aimed not at cultivating either the world or the self, but rather at cultivating relationships to the world. The goal is not refinement of the individualistic or atomistic self, nor disengaged mastery of the world, but rather opening up and establishing axes of resonance. Children are not vessels to be filled, but torches to be lit". With the intension to form an education, with an experimental approach, we teach the students to experience architecture, showing them glimpses of the amazing world of architecture. To awake their curiosity and to connect knowledge with the student's individual creativity, we try to make learning more of a treasure hunt, in which the students explore the subject architecture and at the same time forming their own creativity and opinions. With the intension to give the students a resonant relationship to the world and their own processes, we approach architecture with methods of performative learning. Exploring methods by using painting, building models, writing poetry, working with site specific objects, doing performances etc. to generate architectonic concepts intend to awake the students desire to explore the unknown.



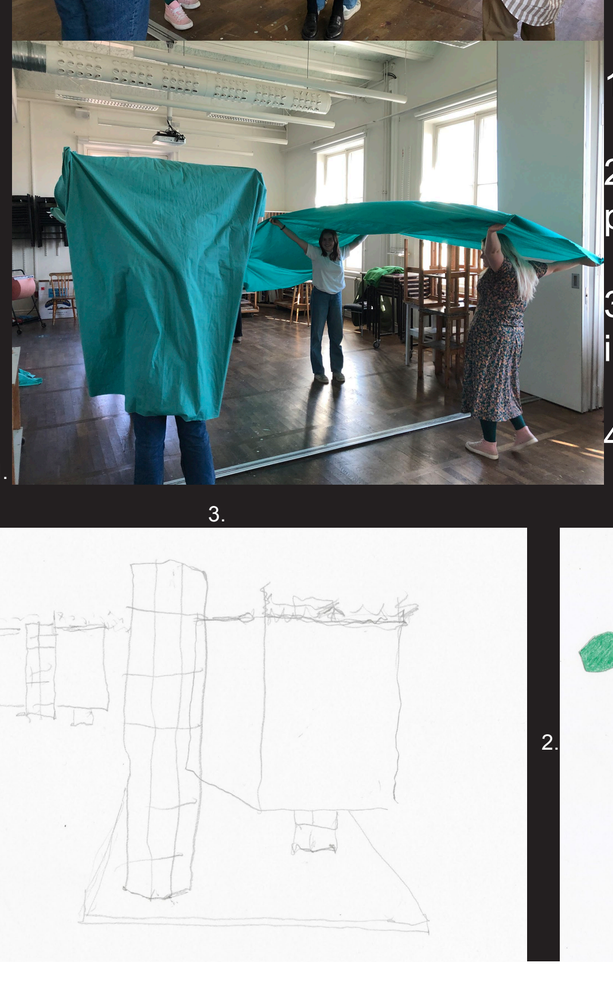
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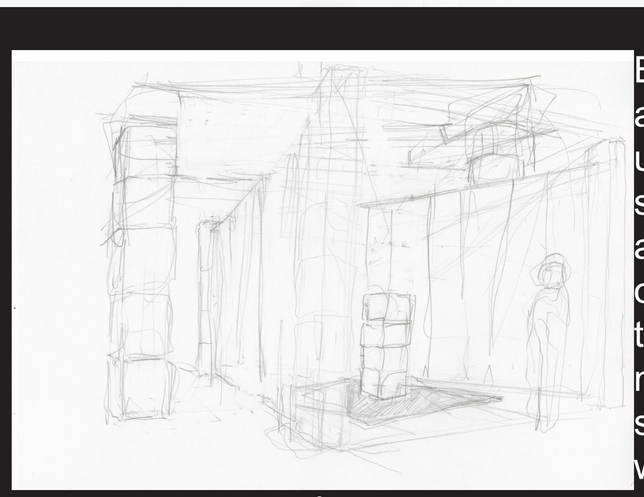






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Based on the art of choreography the students were given an assignment to develop a spatial performance of 120 seconds using their bodies and some textiles to create performative spaces. The students were assigned to work with movement and positions of their bodies in space to create a sequence of space and volumes. Together they improvised and created their own choreography. Part of the assignment was to document and analyse their performance in terms of movements, space, structures and shapes. Presented images and drawings are made by Björn Lundell and Jack Dalla Santa.



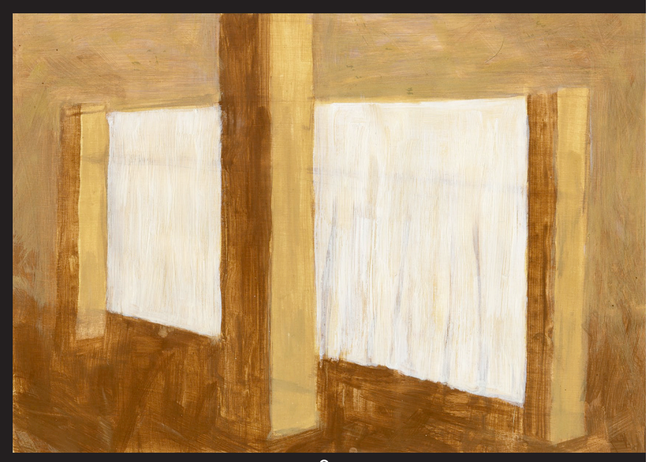
4.

1. Images from the performance.

2. Analysis of time, movement, space, structures and shapes in the performance. Presented as drawings.

3. Transformation of time, movement, space, structures and shapes into architecture. Presented as architecture sketches.

4. Model of architecture based on, and developed from sketches.



3.



2.

SITUATING ARCHITECTURAL PRESERVATION RESEARCH AND EDUCATION WITHIN AN ARTS CONTEXT: CHARLOTTE'S CENTER FOR COMMUNITY, HERITAGE, AND THE ARTS (CHART)

Dr. Emily Gunzburger Makas
University of North Carolina at Charlotte, Charlotte, NC

KEYWORDS: critical heritage studies, historic preservation, performing arts, arts and architecture

ABSTRACT:

The Center for Community, Heritage, and the Arts (CHArt) at the University of North Carolina at Charlotte is focused on preservation and interpretation of the built environment through hands-on engagement with communities, their legacies, and specific places. CHArt furthers the understanding of how the inherited constructed environment intersects with identities and cultural practices by situating architectural preservation conversations and preservation education within a broad interdisciplinary arts context.

CHArt brings together faculty and students from across the university to provide experiences for graduate students in the Master of Science in Architecture - Critical Heritage Studies concentration to engage in interdisciplinary curriculum and research that engages in local solutions and global discourses, methods, and practices focused on tangible and intangible heritages. CHArt and the MS in Architecture – Critical Heritage diversifies approaches and practices of interacting with the past and with places as well as promoting the stories and sites that foreground the heritage of communities underrepresented in heritage professions, practices, and conversations.

This poster shares examples of CHArt's research, including projects in which the MS in Architecture – Critical Heritage students have been engaged. It will demonstrate applied practices, including Ring Shout dance traditions to incorporate traditional African practices into commemorating important African American sites; music and dance concerts based on oral histories and mappings of a diverse Charlotte neighborhood; a series of exhibitions and site markers focused on fostering community conversations about the legacy of lynching; and an original musical theatre production about textile mill and labor movement history performed on site at a historic mill.

Situating Architectural Preservation Research and Education within an Arts Context

We value traditionally appreciated local and global heritage as well as the heritage of previously underrepresented and misrepresented communities. We hope to empower those communities to participate in preserving the tangible and intangible legacies of the past.

We seek to attract and train a more diverse group of heritage professionals, remove barriers to heritage education, and build a curriculum that de-centers traditional preservation practices while privileging other voices and including communities in the conversation.

To support these goals, we at the University of North Carolina at Charlotte launched the intertwined Master of Science in Architecture - Critical Heritage Studies in and the Center for Community, Heritage, and the Arts (CHArt) within the College of Arts + Architecture.

"A creative heritage approach encourages the integration of heritage and creative arts methodologies and theories to produce new knowledge that sits alongside histories, rather than standing in for them."

– Lauren Istvandity, *Integrating Heritage and the Performing Arts* –

Critical Heritage Studies MS in Architecture

Mission

To diversify the field of heritage professionals and the heritage preserved by providing training that situates historic preservation in a critical and transdisciplinary context, engages the global and local, diversifies approaches and practices, and promotes experiential learning, community engagement, and social and environmental sustainability.

Curriculum

- **Required Courses:** Critical Approaches to Heritage, Historic Preservation, Project-Based Research Lab, Heritage Internship, Capstone Colloquium
- **Electives:** Ethnographic Methods, Cultural Resource Management, Museum Studies, Oral History, Digital History, Arts Administration Foreign Study, Architectural History
- **Dual Degree Options:** with Architecture, Urban Design, Public History, or Anthropology

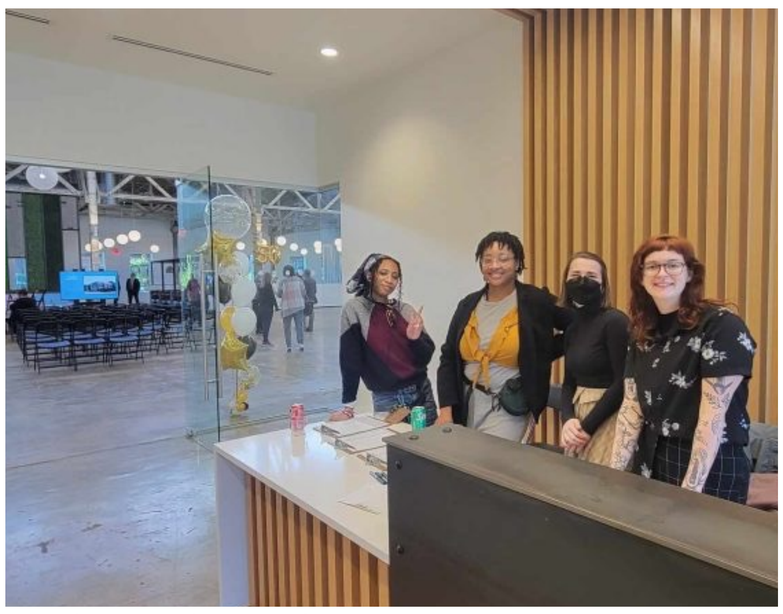


Fig. 1. MS in Architecture Critical Heritage Studies students volunteering at the Charlotte Mecklenburg Landmarks Commission 50th Anniversary Celebration. Photo by Emily Makas.

"Heritage is something vital and alive. It is a moment of action, not something frozen in material form. It incorporates a range of actions that often occur at places or in certain spaces. … It is this tension between action and material representation that is an important element of heritage."

– Laurajane Smith, *The Idea of Heritage* –

Center for Community, Heritage, and the Arts (CHArt)

Mission

- To foreground interdisciplinary conversations focused on preservation and interpretation of the built environment and specific places through hands-on engagement with communities and through the visual and performing arts.
- To strengthen existing collaborations and build new research initiatives exploring the intersections between community, place-making, culture, heritage, and the arts – both globally and locally.

Priority Research Areas / Guiding Questions

- **Heritage Placemaking through the Arts:** How do intangible and tangible heritage practices intersect? How do the arts enhance the experience, memory, and preservation of historic sites and spaces? How do the arts revitalize and maintain community vitality through creative placemaking and tradition building? How does heritage inform new creative practices? How are communities engaged in the co-production of arts and heritage research and practice with artists and academics?
- **Elevating Community Stories:** How do the arts battle erasure of threatened communities and places? How do arts and heritage practices negotiate conflicting narratives and perspectives among varying communities? How do the arts engage collective memories of troubled history and sites of trauma? How can the arts investigate and serve as a vehicle for the heritage of diaspora and immigrant communities, particularly in the Charlotte metropolitan region? How do migrant and diasporic communities retain and engage identity and tradition as well as transform to new homes through arts practices?

Current Integrated Research Projects



Fig. 2. Ring Shout Tradition at Historic Rosedale. Photo by Meg Whalen

Rosedale Roots: Ring Shout Traditions and Legacy Curation

Tamara Williams (Dance) and Sequina DuBose (Music) performed African American Ring Shout at Historic Rosedale, a house museum in Charlotte. The tradition of dance and call and response originated in Africa and was practiced by the enslaved. The ceremony honored the ancestors who labored at the former plantation and was hosted by Rosedale's African American Legacy Project, which is documenting and sharing stories about the enslaved at Rosedale and their descendants. A Graduate Research Assistant from the Critical Heritage MS program collaborated on mapping family trees and presented at the Ring Shout event.



Fig. 3. Entrance to Browne's Ferry Neighborhood. Photo by Emily Makas

Browne's Ferry: Neighborhood History through the Arts

Meg Whalen (CoA+A), Nadia Anderson (Architecture), Mira Frisch (Music) and Ashley Tate (Dance) are exploring the history and heritage of the diverse Charlotte neighborhood of Browne's Ferry and the adjacent Grace AME Zion Church. New dance choreography and musical pieces are emerging from the research and being performed for the community in collaboration with a rap artist from the neighborhood. A Graduate Research Assistant from Architecture is assisting with collecting oral histories from neighborhood residents and parishioners as well as with mapping movement of families and communities to and from Browne's Ferry.



Fig. 4. Exhibition at the Levine Museum of the New South. Photo by Emily Makas.

It Happened Here: Legacy of Lynching in Mecklenburg County

Emily Makas (Heritage) and Marc Manack (Architecture) are working with the Charlotte-Mecklenburg Community Remembrance Project, an affiliate of the Equal Justice Initiative in Montgomery, Alabama to document, mark, and foster community conversations around the two known victims of lynching in Charlotte and their contexts. The team, along with Adam Justice (CoA+A) researched, designed, and installed an exhibition at the Levine Museum of the new South. Currently, a Graduate Research Assistant from the Critical Heritage MS program is reimaging that exhibition to travel to public libraries.



Fig. 5. Historic Postcard of the Loray Mill. Public Domain.

Threads: The Loray Mill Strike Musical

Sequina DuBose (Music) and Laura Waringer (Theatre) have commissioned a new musical theatre work based on the 1929 labor strike at the Loray Mill in Gastonia, NC, which was led by Ella May Wiggins, a textile worker and balladeer. The musical will be performed on site by students at the historic mill, which has been adaptive reused as a thriving condominium. The performance will incorporate acrobatics by the cirque company led by Carlos Cruz (Theatre). Integrating architecture and critical heritage students and faculty into the preparation and setting of the space for the performance is a forthcoming project.

Spatial Agency in Empowering Vulnerable Communities of Kenya

Donghwan Moon
NC State University, Raleigh, USA

KEYWORDS:

1. Participatory Mapping
2. Public Interest Design
3. Community Empowerment

This research aims to investigate and apply a participatory action methodology, focusing on vulnerable communities in Kenya. Learning from various projects implemented in marginalized rural areas, we have developed design frameworks that can make a greater sustainable impact. Our exploration centers around the power of community engagement and participatory mapping, which highlight community knowledge, narratives, and guide the direction of new design interventions. Our ultimate objective is to create inclusive, equitable built environments, with special consideration for the needs of vulnerable populations.

Investigating rural Kenyan communities, significant social, economic, and environmental challenges were identified due to remote locations and neglect from government authorities. The absence of support and development plans leaves these areas without the resources to address urgent needs such as healthcare and education. Additionally, the lack of formal land ownership rights and unclear property borders exacerbate the situation and make it increasingly difficult for people to invest in their community, creating an uncertain future.

To address these issues, our research and projects propose comprehensive solutions to safeguard community land, establish ownership rights, and reinforce local culture. Participatory mapping and inclusive design methods are employed, involving workshops, interviews, and ongoing monitoring with community members and stakeholders. This approach identifies challenges and cultivates opportunities for collective spatial use and sustainable development.

Our projects include the creation of village maps, inclusive public spaces, house prototypes that utilize local resources, and community facilities offering essential programs. The insights gained from these projects act as a catalyst for raising awareness among community leaders, local government officials, and NGOs, with the hope of inspiring similar initiatives in rural contexts worldwide.

Maya Community Map

Visualizing Community Narratives

A 100-acre peninsula colloquially referred to as Maya Island is located east of Kilifi district in Kenya. With only 500 people residing within the beautiful landscape, it has maintained its purity: untouched with plenty of natural resources. However, due to its remote geographic location and harsh economic status, the community has become neglected by the local government, without adequate support or development plans. Recently, the community has also been threatened by land-grabbers and is now in danger of losing their land, despite having proper documentation.

By introducing sustainable building technologies and comprehensive planning ideas, the community is empowered to transform their place into a safer and more hopeful place. The team also created a community map depicting significant geographic landmarks, public spaces, and residential units. This map—the first of its kind for the region “empowered the community, and strengthened its residents’ ties to one another.”



Maya Community Land

1.Community Meetings
-Welcoming participants and workshop identification



2. Community Workshop
-Facilitating small group sessions and gathering data



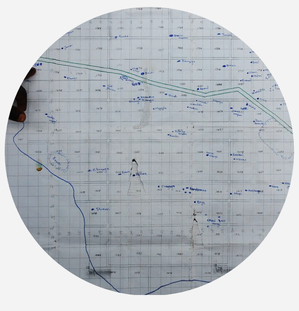
3. Mapping with the Community
-Engaging the community through participatory mapping



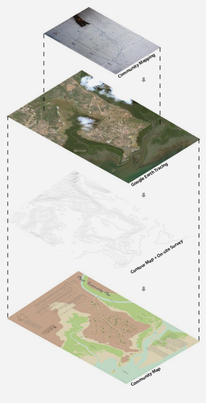


Participatory Mapping Outcome

4. Data Collection
-Identifying households and community stories



5. Transforming the Gathered Data into Digital Format



6. Deliberations on Potential Projects
-Verifying data/mapped locations and discussing prospective projects



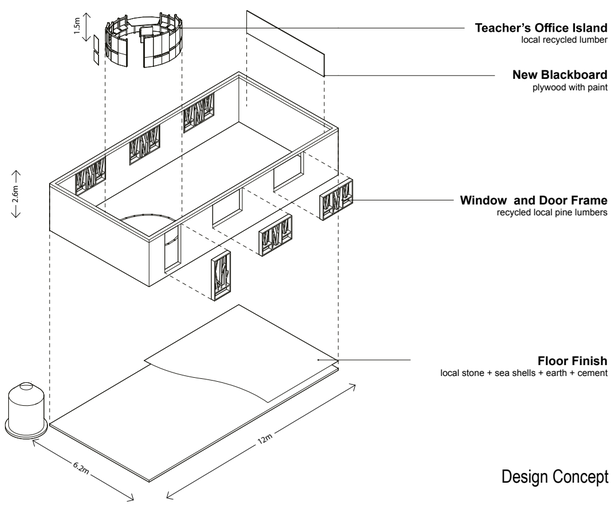


New Community Map

Maya Primary School

New Social Infrastructure for the Next Generation

Following community meetings, surveys, and individual interviews, it became evident that the top priority was enhancing the quality of the current primary school and its surroundings. Collaborating with local volunteers and skilled workers, the team embarked on a project to revitalize the school and construct an outdoor playground. Local materials like sea stones, native soil/sand, and seashells were employed in the renovation. The new spaces were meticulously designed to embrace and showcase the cultural values and distinctive traits of the community through integrated design features.



Design Concept

1. Community Workshop
-Small group discussion and interviews



2. Data Collection
-Gathering data + identifying needs



3. Inclusive Design Process
-Participatory design charrette +sharing design concepts





Previous Condition

4. Using Indigenous Materials
- Identifying and gathering locally sourced stones and seashells



5. Community Participation
-Collaborating with local volunteers and constructing collectively



6. Creation of New School
- A redefined social infrastructure for the new generation



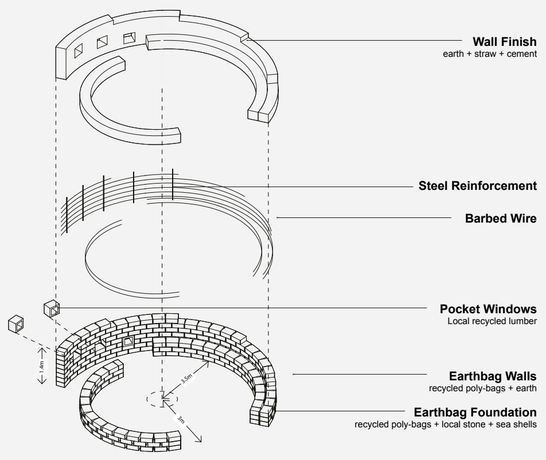


New School

Maya Community Agora

New Public Gathering Place for All

The school’s outdoor space lacks a distinct identity, with a shortage of seating, communal areas, and designated spaces. After engaging in design charrette sessions with community members, we collectively decided to establish an outdoor gathering space—an agora—where everyone is welcome to meet, relax, play, and celebrate. Utilizing earthbag construction for the primary framework, the entire design and construction process was orchestrated by community volunteers. The resulting agora has become the school’s iconic centerpiece and is now the community’s favorite destination.



Design Concept

1. Design Charrette
- Involving the younger generation in the design process



2. Using Local Materials
- Identifying locally available resources for the main structure and foundation



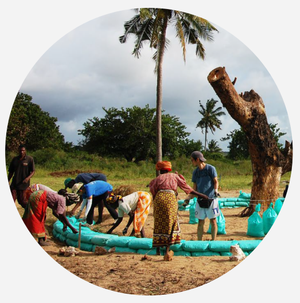
3. Technology Sharing
- Introducing the technique of earth-bag construction





Previous Condition

4. Collaborative Community Effort
- Building and laying the blocks together with the community



5. Finishing with Children
- Completing the structure a mixture of soil and straw



6. Creation of New Community Place
- A new place for gathering, resting, playing, and celebrating





Community Agora

Transforming the Humble Brick: Mosquitoes-Protective Building Materials

Michael Serrano[1], Elijah D. Rutkowski[1], Elizabeth L. McCormick[1,2] [0000-0002-7548-2951]
[1]University of North Carolina at Charlotte, USA
[2]North Carolina State University, USA

KEYWORDS: Mosquitoes, Malaria, Brick, Tanzania

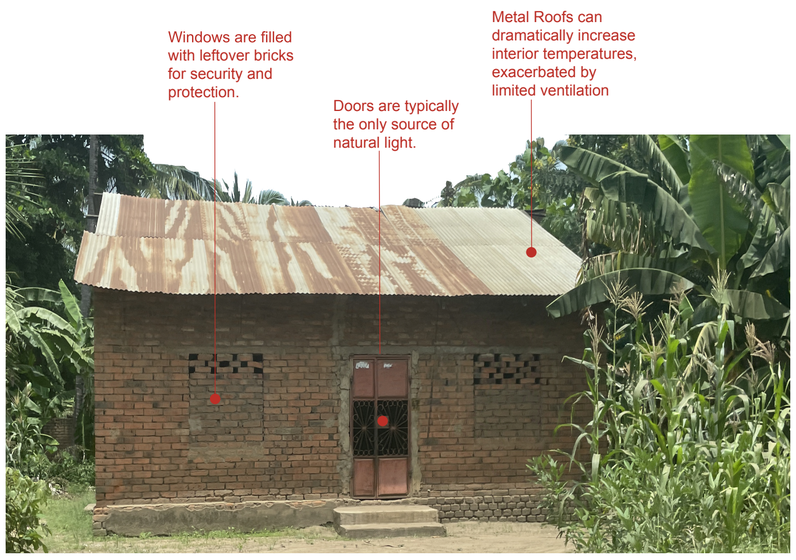
Studies indicate that climate change impacts will dramatically increase vulnerabilities in rural communities where those living off the land are at increasing risk from extreme weather events such as heat waves, famine and drought. Additionally, more than 80% of the world is at risk from at least one vector-borne disease, and Malaria is a leading cause of death in the developing world. However, most research in this field addresses this public health crisis in the form of pesticides, chemical interventions, and genetic modification, with little consideration for the role of the built environment, particularly in limited resource settings. Recent efforts to make housing more protective, however, often lead to dwellings that have reduced air transmission and poor indoor environmental quality. Additionally, modern, sustainable buildings can be technologically complex and prohibitively expensive.

The brick, however, is the most commonly used building material in the world. By studying the material aspects of this humble material in tandem with the synergistic relationships of energy, comfort, and disease, this humble material has the potential to become a greater part of the urban resiliency and public health strategy. Working collaboratively with engineers, entomologists, social scientists, and regional experts, student researchers explored the capability of masonry construction materials made from accessible, low-impact resources to control the transfer of heat, moisture, and mosquitoes in housing in rural Tanzania. By challenging conventional norms of construction and global health, these prototypes explore the intersection between design, disease and a rapidly changing climate.

PROJECT STATEMENT

The brick is the most commonly used building material in the world - in fact, one-third of the world's population lives in buildings entirely or partially made from earth (Barnaure et al. 2021). Developing countries, especially in regions like sub-Saharan Africa, aspire for a modern presence on a global stage while facing distinct health challenges related to housing, particularly related to vector-borne diseases. These issues are typically addressed through extensive global health initiatives, operating independently of considerations related to the built environment.

The unprecedented population growth in sub-Saharan Africa presents a unique opportunity to integrate innovative material and housing concepts that can dramatically improve human health and well-being. In response, this project addresses the interdisciplinary innovations that reconceive modular earthen materials and challenge existing norms of construction and material science, exploring the intersection between design, disease, and a rapidly changing climate.



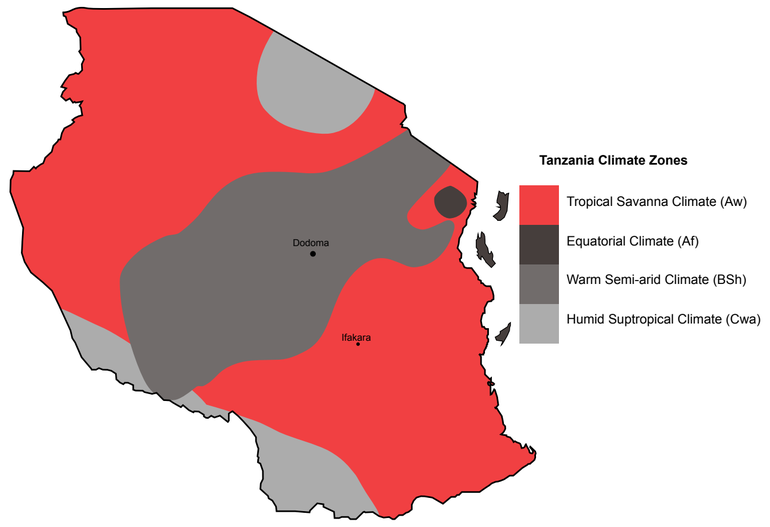
BACKGROUND

Mud-brick homes are prevalent across many sub-Saharan African countries. Recent research conducted by Bofu et al. (2023) in southern Tanzania reveals that a significant majority of surveyed homes (78.1%) feature brick walls and metal roofs, attesting to the widespread use and acceptance of these materials in the region as opposed to the more traditional wattle and daub construction typology. As African nations modernize, the allure of contemporary alternatives often overshadows the rich local architecture and materials. While mud and burned brick are familiar building materials in sub-Saharan Africa, they are heavy and easily store heat and obstruct airflow, making them challenging for hot-humid climates (von Seidlein et al. 2019).

Historically, housing improvements have been a critical aspect in the realm of public health (Shaw 2004; Krieger & Higgins 2002). However, this domain has not been fully leveraged in malaria control efforts while competing household priorities further complicate the situation. Although other control measures such as window screens and sealing of cracks prove valuable, they often require financial investment that many families find burdensome. Consequently, introducing a supplementary option that enhances thermal comfort and indoor air quality without entirely displacing existing strategies becomes imperative.



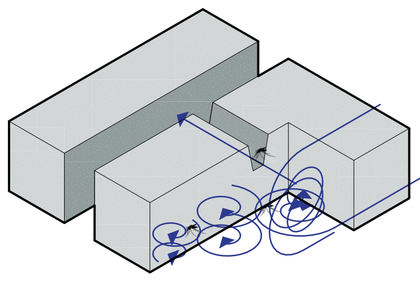
CLIMATE

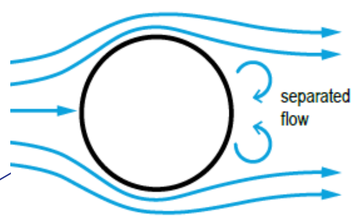


Located in East Africa just south of the equator, Tanzania contains several distinctive climatic zones, including hot desert, cool mountains, and humid subtropical. Vector-borne disease is one of the biggest threats to Tanzania residents. Long identified as a disease associated with poverty; today over 90% of malaria cases and fatalities are concentrated in the world's poorest countries, with a preponderance of disease burden in Sub-Saharan Africa (Worrall 2005). Paradoxically, as homes are built in phases and openings are covered up, interior conditions become inhospitable and unhealthy, particularly when cooking occurs indoors. In response, this project looks to improve the breathability of the building envelope while maintaining vernacular styles and cultural expectations.

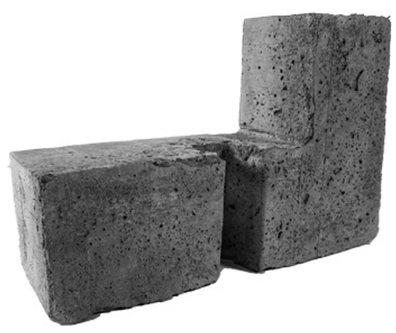
STUDENT PROPOSALS

VORTEX BRICK by Michael Serrano

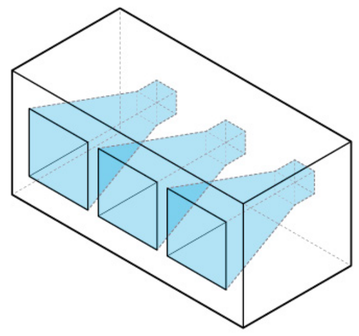


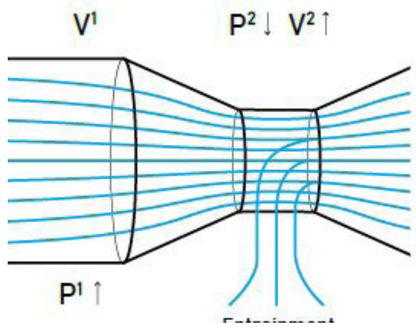


Mosquitoes generally prefer calm environments for movement and have difficulty navigating turbulent conditions. This project utilizes the phenomenon of vortex shedding, which involves the creation of vortices, or convective pockets, on the back side of a mass. This pocket is then used to trap mosquitoes while allowing fresh air to pass through the wall. The strategic placement prevents mosquitoes from accessing interior areas and reduces the transmission of vector-borne diseases. To create an effective barrier, the cortex bricks should be laid in a row-style pattern, closing the tunnel of the brick. this configuration will provide enhanced protection in areas where mosquitoes are most likely to enter.



VENTURI BRICK by Nate Smith

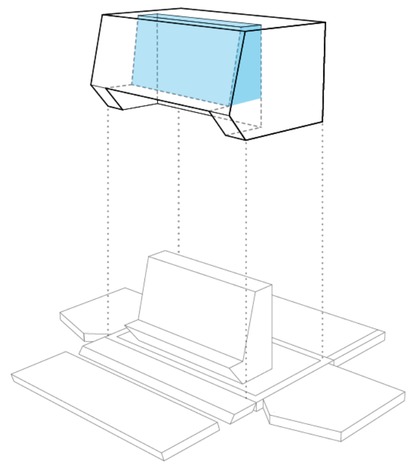






The Venturi Brick is a module that uses a truncated, horizontal hollow core to employ the principles of the venturi effect, which state that a decrease in pressure will lead to an increase in velocity. These cone-shaped cores increase the air movement within a building, which create a much needed cooling effect but also creates turbulent air conditions that challenge mosquito flight. This block has the potential to passively address the issues of human comfort and vector control without dramatically shifting local building practices.

POROTHERM BRICK by Vishna Krishna Kamatham



The term Porotherm is used for this type of brick due to is porosity and desired thermal characteristics. The aim of this wall system is to provide air movement through the bricks while maintaining a certain level of visual privacy so that it can be used as external wall system. Air can circulates through the brick, fueled by buoyancy flow, wile the slope of exterior face protects the wall from solar heat and rain. A recess is provided underneath to let the rick breath and promote a continuous flow of air, so that thermal comfort is achieved passively.



ADDITIONAL BRICK PROTOTYPES



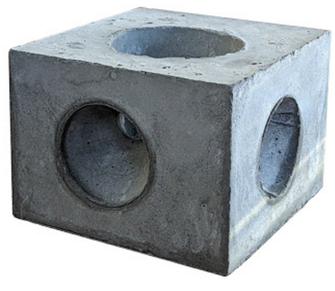
Flow brick
Eric Jackson



Water Collecting Brick
Sarika Merchant



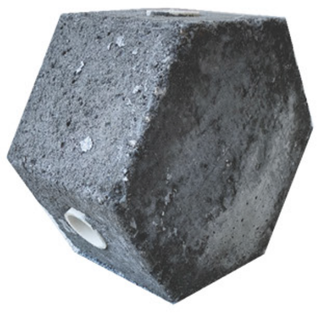
Bee Brick
Elijah Rutkowski



All Around
Amir Heydarpour



Solar Brick
Keenan Madden



Waters Brick
Sarah Auger

CONCLUSION

Across culture and context, the home is a source of pride - it is a material instantiation of social progress, a reflection of the aspirations of its inhabitants (Archambault 2018). Capitalizing on those commitments to craft a home that is safe and livable, not only has potentially major public health dividends, but can foster new understandings of the act of construction and its role in ensuring local wellbeing. Working with brick can help bring about a critical paradigm shift in global health from the technocratic minimalism of humanitarian design, to locally-driven and adapted interventions that make substantial improvements in everyday living–a process of innovation where global health, urban resilience, environmental sustainability and dignified existence converge.

The brick emerges as a catalyst for change, challenging conventional norms in construction and public health. Its integration into local communities signifies a paradigm shift towards community-driven, culturally attuned, and sustainable solutions at the nexus of architecture and global health. While it remains to be seen the degree to which these bricks can be rendered legible as global health tools, it is our hope that they might foster a different set of questions around the relationship between global health and development—and the importance of comfort in cultivating a more secure future.

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EAAE-ARCC CONFERENCE 2024

ARCHITECTURE INTO THE UNKNOWN