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.

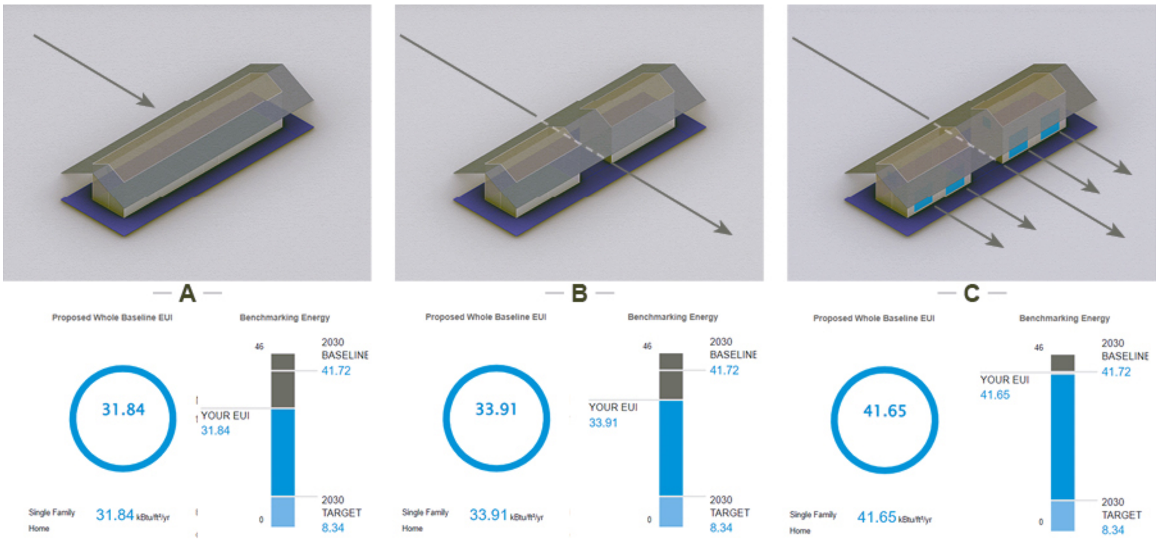

Figure 1: Sensitivity testing of natural cross-ventilation strategies. Source: (Frank 2023)

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.

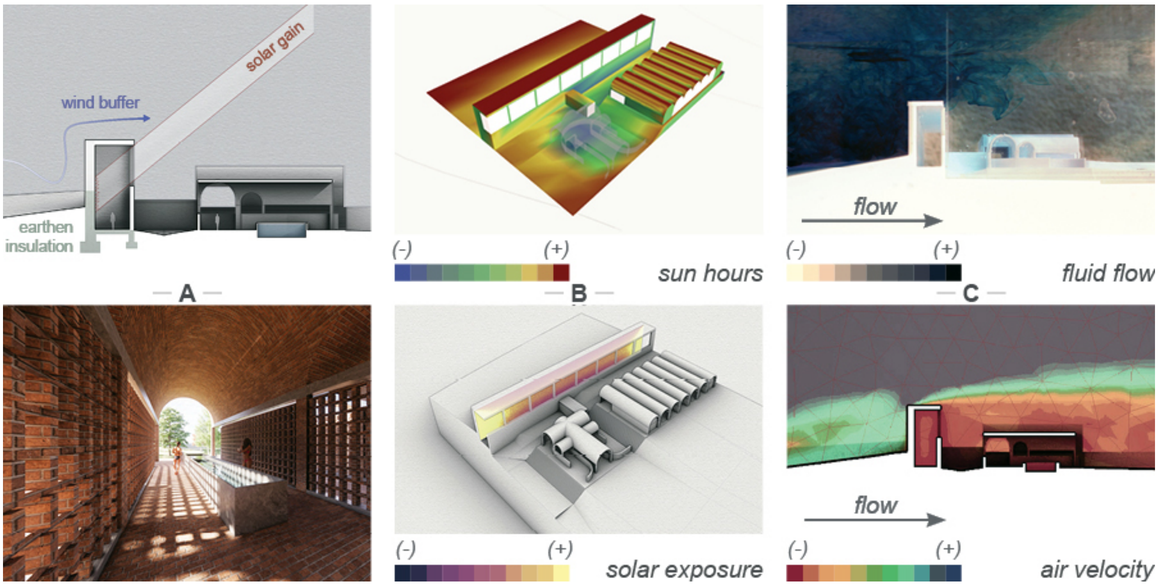

Figure 2: Vignette 1 demonstrating the use of reciprocity testing protocols. Source: (after Sweat 2023)

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).

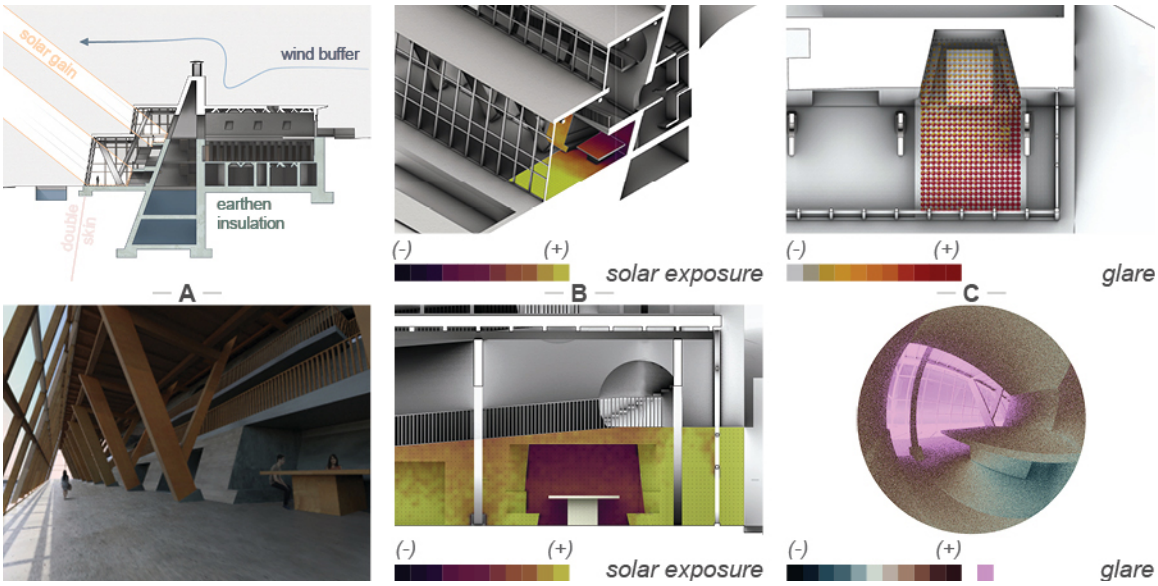

Figure 3: Vignette 2 demonstrating the use of concurrent multi-parameter design making. Source: (after Haller 2023)

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.

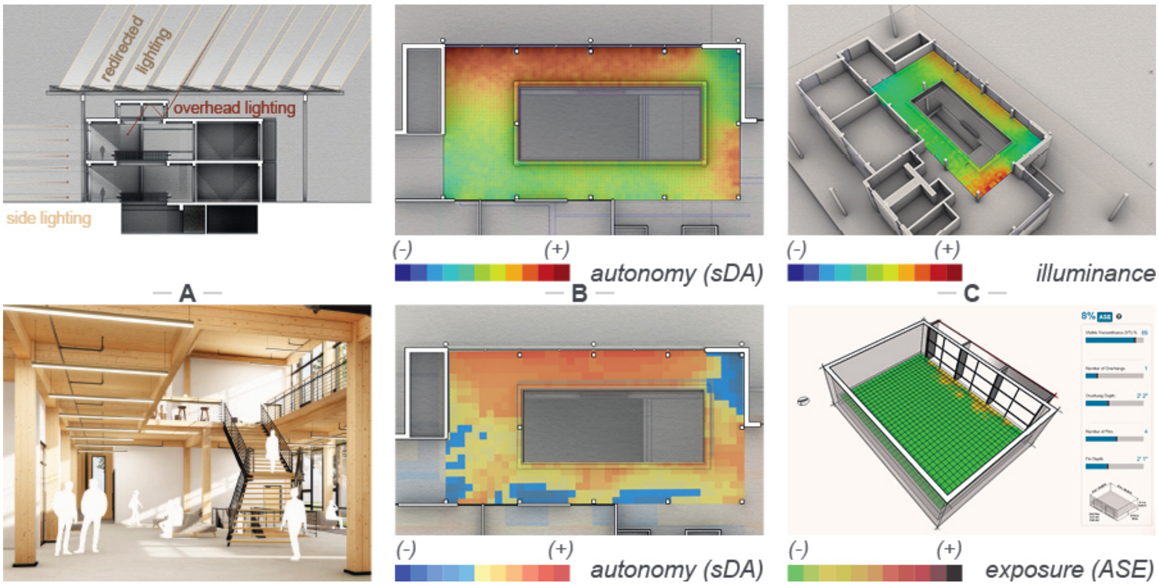

Figure 4: Vignette 3 demonstrating the use of result corroboration. Source: (after Jerabek 2022)

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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