Bridging Analog and Digital Realms: Fostering Sustainable Design Innovation Through Integrated Teaching Techniques

Mariya Stoyanova Bond[1], Anshuman Abhisek Mishra[1], Leif Martin Hokstad[1], Luca Finocchiaro[1]

[1]NTNU - Norwegian University of Science and Technology, Trondheim, Norway

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.

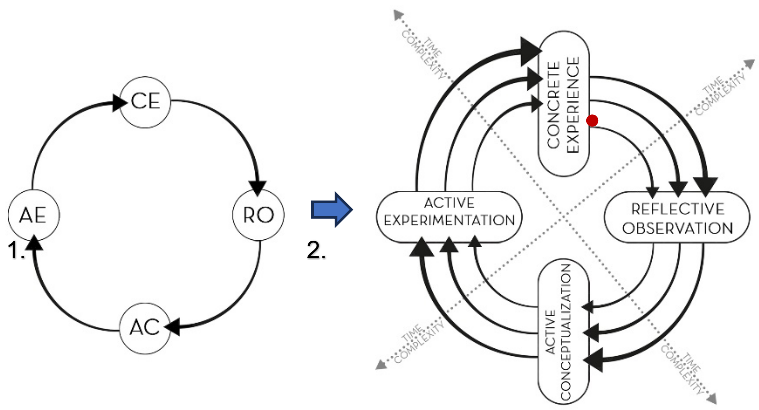

Figure 1: 1. Kolb's Learning Cycle; 2. Schenck and Cruickshank's Co-constructed Developmental Teaching Theory. Source: (Assembled by the authors 2023)

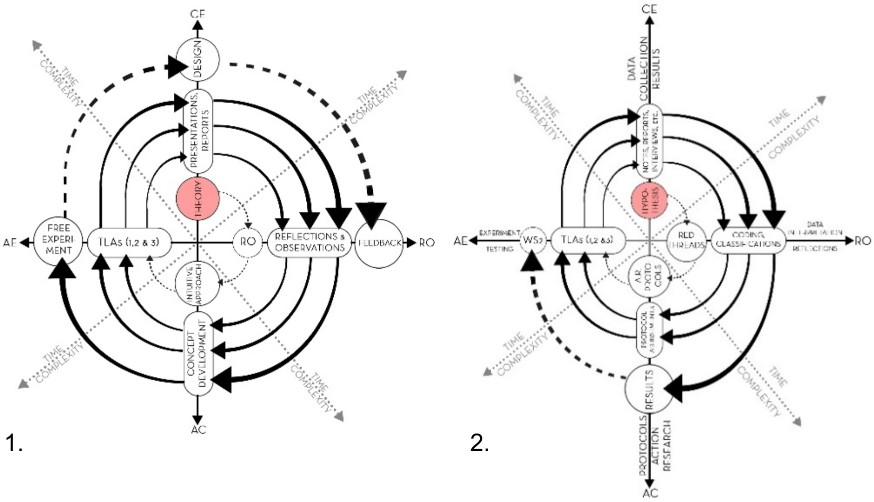

Figure 2: 1. Workshop activities' scheme; 2. Research design structure scheme. Source: (Assembled by the authors 2023)

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.

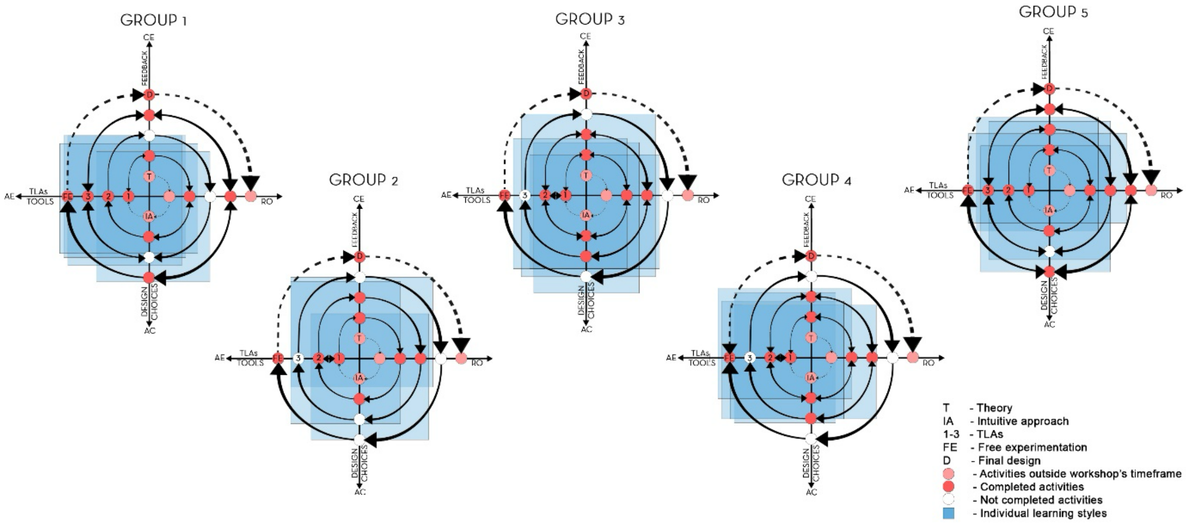

Figure 3: Visual representation of the results of the experimental workshop placed on top of the results of the learning style inventory test for each student in each group. Source: (Assembled by the authors 2023)

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.

ACKNOWLEDGEMENTS

This workshop and study have been developed within the DigiHands project supported by the Norwegian University of Science and Technology - NTNU through the Toppundervisning and SO Stilling. We would like to thank all the students who participated and the administration for supporting the workshop development.

REFERENCES

Cohen, L., Manion, L., and K. Morrison. 2018. “Action Research.” Essay. In *Research Methods in Education,* 297-313. London: Routledge.

Edwards, B. 2010. *Rough Guide to Sustainability*. London: RIBA Enterprises.

Fullan, M., and M. Langworthy. 2014. *Leadership and Policy in Schools*. London: Pearson.

Fuller, R.B. and J. Snyder. 2019. *Operating Manual for Spaceship Earth*. Zurich: Lars Müller Publishers.

Heidegger, Martin. 2019. *Being and Time*. Translated by John Macquarrie and Edward S. Robinson. Eastford, CT: Martino Fine Books.

Jansson, David G., and Steven M. Smith. 1991. “Design Fixation.” *Design Studies* 12 (1): 3-11. https://doi.org/10.1016/0142-694X(91)90003-F.

Kolb, David A. 2021*. “Experiential Learning: Experience as the Source of Learning and Development.“* Upper Saddle River, NJ: Pearson Education.

Olgyay, V. 2015. “Sol-Air Orientation.“ In *Design with Climate: Bioclimatic Approach to Architectural Regionalism.* Princeton, NJ: Princeton University Press.

Saldaña, J. 2013. The Coding Manual for Qualitative Researchers. Thousand Oaks, CA: SAGE.

Schenck, Jeb, and Jessie Cruickshank. 2014. “Evolving Kolb.” *Journal of Experiential Education* 38 (1): 73–95. https://doi.org/10.1177/1053825914547153.

Soares, J. 2016. “Try Thinking Like a Tree.” In *The Power of Experiment: Artéria - Humanizing Architecture*: 4th edition of Lisbon Architecture Triennale. Lisbon: Edition Artéria

Somekh, Bridget. 2006. *“Action Research; A Methodology for Change and Development“.* Maidenhead: Open University Press.

Tavares André and D. S. Lopes. 2016. “A Portuguese Utopian Rest.” in *The Form of Form*. Zürich: Lars Müller Publishers.