Bridging the Gap: Sustainable Thinking in Architectural Education

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In the evolving landscape of architectural education, the imperative to cultivate sustainable design competence has become increasingly prominent. While the term “sustainability” has become ubiquitous in design studio briefs, there remains a significant gap in providing students with clear definitions and the means to integrate sustainable principles into their design projects successfully. To effectively address this issue in architectural education, it is essential to develop methodologies that are adaptive to the changing climatic challenges and rapid technological advancements, all while effectively navigating the persistent perceived dichotomies that dominate architectural education and the profession, such as the discourse between creativity and technicality or analytical and synthetical minds. Architectural programs are positioned to respond to these challenges and bridge the divides by persisting in the deep learning of fundamental principles and theories and by creatively incorporating sustainable environmental design into traditional design studios. This paper explores the current state of sustainable environmental design within architectural education and underscores the vital need to equip students effectively with the necessary tools and methods to integrate sustainability into their designs consciously and meaningfully. It discusses two modules that emerged from the restructuring and testing of the environmental technology sequence within the curriculum of a graduate architecture program. One focuses on studying existing buildings through a structured post-occupancy evaluation project, leveraging historical contexts, and the other is centered on integrating computational simulation tools into the design process, harnessing contemporary technologies. Both modules emphasize immersive, experiential learning, nurturing process-based mindsets that promote flexibility and adaptability to the rapid changes the architectural profession faces, and empowering students with analytical skills to navigate the complexities of sustainable design. Students are encouraged to cultivate critical thinking skills and embrace interdisciplinary perspectives by employing active learning strategies, emphasizing learning-by-doing approaches, and promoting student-led initiatives, ultimately prioritizing design processes over singular outcomes.

ACADEMIC CHALLENGES AND REALITIES

In the past decade, an increasing number of architecture design studio briefs call for building designs that are “sustainable,” “green,” “ecological,” “bioclimatic,” or “net-zero,” leading to the ubiquity of the term *sustainability*[1]. However, students are not always presented with a specific definition of this ask or provided the means to deliver successfully. Few architectural programs have tried to bridge the dichotomies and integrate sustainable environmental design with traditional design studios[2,3]. Despite such remarkable efforts, and as Fleming (2021)[3] notes, there has been little consideration or investment in providing the tools for doing so; there is a gap between the intentional and the operational.

Several educators[3,4,5] have outlined the numerous obstacles sustainable architectural education encounters, such as its ambiguous identity and objectives, confusion regarding the concept of sustainable architecture concerning its integration into the curriculum, academic inertia, limited expertise among educators, social conformity, as well as the lack of inspiring prototypes to counterbalance the mesmerizing models of non-sustainable lifestyles. This long list of obstacles is complemented, and even exacerbated, by three topical and understudied challenges faced by sustainable architectural education:

- the rapid change rates and unpredictability of the climate crisis implications,

- the concurrent technological advancements,

- and the ongoing competition of prevalent constructed dichotomies in the profession.

RACE WITH TIME: CLIMATE CRISIS AND TECHNOLOGY

In the ever-evolving world of architecture, two paramount forces have radically reshaped the practice in recent years: the climate change crisis and the relentlessness of technological innovation. These two phenomena share a common thread: their exponential growth and unpredictable interaction with humanity. As architects, designers, and urban planners grapple with these formidable challenges, they stand at a critical juncture that demands creativity, adaptability, and a profound commitment to resilient, human-centric design.

The built environment must undergo a significant transformation to minimize its ecological footprint, all while ensuring comfortable and healthful indoor environments and safeguarding against ever-intensifying and ever-increasing extreme weather conditions. The climate change crisis is no longer a distant specter on the horizon; it is a present reality that architects must adapt to and negotiate with, or otherwise, they will have to face forcibly. Rising global temperatures, extreme weather events, and the depletion of natural resources have become pressing concerns, forcing a paradigm shift in architectural thinking but not in the tactics of developing impactful solutions. In parallel, technological innovation has applied unprecedented pressure to our design and fabrication practices. Cutting-edge tools like Building Information Modeling (BIM), Building Performance Simulations (BPS), 3D printing, and the exponentially increasing influence of Artificial Intelligence (AI) within these tools have revolutionized the design process, offering architects newfound precision, efficiency, and the possibility of approaching design in a non-linear fashion. The unprecedented technological advancements of the past century are but a glimpse of our future interaction with the tools available to the profession.

The time needed to adapt educational programs to incorporate climate change crisis and technological innovation into the design process is often surpassed by the next climatic challenge or technological advancement, resulting in the degradation of known solutions to obsolescence. While there is an evident need for architecture to integrate current practices and technologies into the design process, there is also a need to selectively move away from an exhausting overview of such tools and focus on the deep learning of fundamental theories, principles, and tools at the intersection of energy flows and human experience. According to Elisa Iturbe[6], our moment demands new architectural and urban organizations for whom the relevant energy transition is yet to come. She suggests that architecture needs to move away from technological practices that serve the current carbon economy and lay the foundation for the coming transition. In the face of the yet unknown imminent developments related to climate change and technology, the author encourages dedication to robust foundational knowledge paired with a comprehensive understanding of building performance computational tools, fostering adaptability to change and opening the way for much-needed innovation, including novel social and economic transformations.

PSEUDO-DICHOTOMIES

“Sustainable architecture: …we would expect such architecture to be performative, that is, capable of providing occupant comfort at lowest carbon emission; and, expressive, that is to reflect the architectural programme and its context in terms of climate, site and culture.” – Simos Yannas[7]

Architectural education has long suffered from perceived pseudo-dichotomies, such as the tension between creativity and technicality, analysis and synthesis, artistry and scientific rigor, and impulsiveness and methodology. In addition, environmental *technology* suffers from its own name and the perception that anything associated with it is math-heavy and lacking sociocultural considerations or creative edge. In the face of today’s climate crisis and its increasing impact on communities, such constructed dichotomies prove false and ineffectual and make the case for a novel approach that dissolves the made-up boundary between them while placing validation and originality as equal conditions for a “good design.” In effect, students who own sustainable design principles as intuitive responses that reflect on their creative expression and experimentation and can validate and augment their intuition using computational performance-based methods and tools will generate more integrated and better-rounded designs than students who don’t.

Studies have indicated that architects typically adopt a solution-oriented rather than problem-oriented approach when crafting their designs. As Sergio Altomonte (2009)[8] underlines, frequently, students are not explicitly encouraged to analyze specific problems. They are instead tasked with presenting solutions, emphasizing the attainment of desired outcomes over critical exploration of the intricacies of the challenges they confront. This cognitive style hinders the development of critical thinking and personal growth among students. There is a need to move the spotlight away from the actual linearity of design solutions and instead emphasize non-linear analytical methods, employing learning tools that prioritize more sophisticated, open-ended, unbiased design processes over biased results. Promoting design processes in architectural education fosters critical thinking and problem-solving skills, encourages lifelong learning unrelated to a specific project brief, programmatic requirement, software, or tool, and suggests actively using such briefs or tools only as a means of effective learning.

Thus, a more robust interdisciplinary approach in architectural education is needed to empower students with the skills and tools for sustainable design[9]. Integrating theoretical and practical aspects of sustainability teaching in architecture departments to promote sustainable design thinking among students is imperative[10]. Research suggests that current architecture students have a growing awareness and desire to learn about sustainable thinking and address the climate urgency. In parallel, there has been an increasing interest among professionals in incorporating simulation technologies early on in the design process, not anymore as a result of collaboration with engineers but via systematic empowerment of architects to possess such tools. Exploring the relationship between architecture students’ knowledge of “sustainable design” and its implementation in their design projects indicates a connection between awareness and action[11]. The strong desire to learn about sustainable thinking creates increased student learning requirements and demand for relevant research, a more dynamic educational environment, and an excellent opportunity to co-create with students. There is a profound need for more targeted delivery of the related content using more integrated approaches throughout the curriculum and through student experiences across campus. This calls for a curricular transformation that facilitates a unified approach to the academic goals and means, strategic faculty involvement, and a synchronized administrative and intellectual consensus by educational institutions to implement unencumbered integration of environmental design into architecture studios using state-of-the-art methods and tools.

TWO-CLUSTER STRUCTURE

The challenges of rapid climate change and relentless technological innovation, as well as those posed by the perceived dichotomy between the creative and the technical nature of architecture, demand persistent focus on two aspects: 1) the deep learning of fundamental theory and principles, and 2) the seamless integration of environmental technology into design studios by injecting analytical skills into the design process. The ever-evolving curricular structure and methods proposed in the following chapters define and test two educational frameworks that use established pedagogical strategies to implement these two aspects. The modules are still under development, but their early implementation has proved vastly successful. The following chapters present the principles, structure, and goals for future growth of the environmental technology (ET) track at the Master of Architecture (MArch) graduate program at the Gerald D. Hines College of Architecture and Design (CoAD) at the University of Houston (UH). This transformation aims to create the framework for every student to know *why* it matters in the era of climate change, *what* architectural design can do for contemporary challenges, and *how* all designers can implement their solutions for sustainable and resilient cities. Every student is empowered with the knowledge and tools to not only collaborate effectively with engineers and experts but also to integrate performance-based sustainable thinking in their designs actively.

Technology is better understood through the concept of Systems Theory. Systems are a conglomeration of interrelated and interdependent parts which can be natural or human-made. To rationalize the content, and as described by the EDUCATE[12] initiative, the knowledge body is taught at the intersection of three pillars: 1) Issues and Principles, 2) Tools and Methods, and 3) Applications and Case Studies. Although all three clusters are components of all courses, the ET sequence is designed to gradually spiral through the knowledge triangle, aiming to reach a creative integration when all three pillars are equally met in the middle (Figure 1).

ET courses measure their success through their potential to dissipate and integrate within the students' design studios. The ET courses taught in the graduate program are offered to level 1 and 2 students, as shown in Figure 2. What started as a parallel-taught, four-course sequence in 2020 has undertaken a gradual and systematic transformation over the past three years. Ultimately, the sequence will begin with one parallel-taught course in Materials and Methods, followed by one parallel-taught course (Building Physics I), a partially

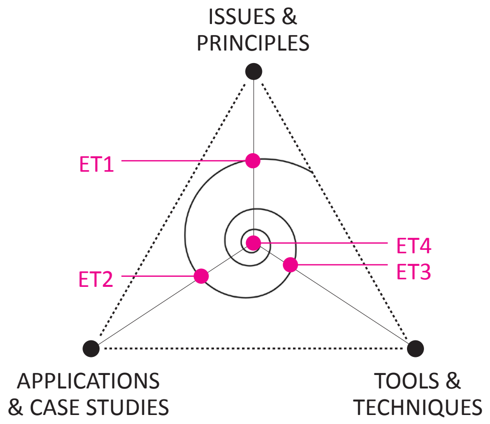


Figure 1: Environmental technology sequence spiraling on the knowledge triangle. Image by author. The knowledge triangle first appears in Altomonte et. al (2012)[11].

LEVEL	BUILDING TECHNOLOGY		DESIGN STUDIO	NAAB criteria	INSTRUCTIONAL MODEL*	PEDAGOGICAL STRATEGIES*
	ENVIRONMENTAL TECHNOLOGY	CONSTRUCTION TECHNOLOGY				
LVL1 (+3 MArch)	Materials and Methods		Conceptualization		Parallel	Global learning Inquiry-based learning
	Building Physics I **(POE)**	Construction I	Materialization		Parallel	Case-based learning Collaborative and cooperative learning Experiential learning Field- and place-based learning Research-based learning
LVL2 (+3 and +2 MArch)	Building Physics II	Construction II	Contextualization	x	Partially integrated	Critical and transformational pedagogy Inquiry-based learning New forms of assessment
	Design integration **(BPS)**		Synthetization	x	Fully integrated	Case-based learning Gamification Immersive learning Research-based learning Technology-enhanced learning

* The terms are used as described in (Altomonte, 2012)[13]
** The terms are used as described in (Mintz 2020)[14]

Figure 2. The general structure of the environmental technology track in relation to studio projects. Image by author.

integrated (Building Physics II), and a fully integrated course (Integration) - the terms "parallel," "partially integrated," and "integrated" are used as described in (Altomonte, 2012)[13]. Level 1 students are introduced to the fundamentals of climate and comfort concerning building design and operation. Level 2 students employ more advanced metrics and tools to understand whole building assessment, such as Energy Use Intensity (EUI), embodied and operational carbon, primary energy use, occupant health and well-being, and building systems.

The following chapters discuss the development and effectiveness of two modules. These modules are chosen to respond to the two main requirements of instilling environmental technology into student education: 1) deep learning of theory and fundamentals and 2) creative integration with design. They also actively engage pedagogical strategies to facilitate learning-by-doing and experiential, student-driven, process-focused learning -instead of a more passive, hierarchical model, which is how it has been taught traditionally. Building Physics I aims to instill theory by developing a comprehensive post-occupancy evaluation (POE) exercise, and Design Integration intends to fully integrate theory into creative practice by using advanced building performance simulation (BPS) tools and evaluation methodologies within the studio environment. These methods and tools are presented as the media to reconcile process-focused, evidence-based analytical thinking with design.

BUILDING FUNDAMENTALS THROUGH A CASE STUDY

Diverting from over-concentration to new construction, Bordass and Leaman[15] advocate for a fresh approach to professionalism within the built environment, emphasizing the importance of deepening the understanding of buildings already in use. Studying precedents has always been a favorite topic in architectural pedagogy, particularly in sustainable environmental design. Internet resources for studying existing buildings are plentiful today but often lack depth and validity. Students report learning faster and better when engaging in first-hand applications[16,17], especially when understanding and quantifying invisible or intangible parameters, such as temperature, carbon dioxide, and illuminance. POE projects adopt a more experiential learning-by-doing approach[18], engaging students actively in real-world scenarios to maximize their understanding and critical thinking abilities[19]. This way, the students return to understanding buildings as *physical objects with physical processes*, a concept that started getting lost when buildings started being designed on computer screens.

In its first year of implementation, the chosen case study building was the students' own College of Architecture. This choice intuitively created a sense of ownership and personal investment for the students, reflected in the project's outcomes. Furthermore, the physical presence of students as researchers around the College assisted with the project dissemination across the community and helped de-sanctify the building's iconic design by showing real-time physical data. The project covered the investigation of four microclimatic parameters – thermal, air quality, lighting (both daylight and artificial), and sound – initially analyzed by teams and later examined as part of individual research agendas, including developing a clear research hypothesis and methodology. It comprised five progressive assessment tasks designed to accommodate time and resource availability. These tasks included secondary data collection, user surveys, interviews, environmental parameter spot measurements, and data logging using environmental sensing equipment. The project produced a myriad of data and illustrations. Selected examples of data collection and analysis as a result of teamwork or individual student research activity are shown in Figure 3. Through data postprocessing methods and self-driven research agendas, students gained insights into the building's functional, technical, and environmental performance, as well as occupants' perception and reaction to the studied physical parameters.

The comprehensive approach equipped students with the necessary skills to analyze and interpret data, enabling them to propose sustainable design interventions and solutions. The process yielded an impressive learning leap in building physics and human comfort fundamentals for first-year architecture students. By the end of this course, they successfully communicated their ideas using proper terminology and analysis methods that could be attributed only to the hands-on, learning-by-doing approach. The students practiced data processing, research questions and methods formulation, presentations, summary reporting, and evidence-based design ideation. They learned to think analytically while resourcefully bridging creativity and technical rigor, materializing intangible environmental attributes through experiential evaluations. Finally, the process exposed a particular appreciation of the more performative and the less iconic, a much-needed attitude in architecture today.

This project planted the seed for further course development, including additional buildings on campus, landmark buildings, and different residential typologies around town. In the pedagogy of building systems, the performative, sustainable, or design merit of studied buildings is not a prerequisite. Virtually any building can be a valid case study to explore how people make buildings work. The only limitation for a more comprehensive implementation of this program in other institutions is the cost associated with acquiring and maintaining the measuring equipment, which could be deemed minor as such resources become more affordable.

INTEGRATIVE ARCHITECTURE THROUGH SIMULATIONS

The American Institute of Architects issued a document in 2019, the "Architect's Guide to Building Performance: Integrating Simulation into the Design Process," which explicitly encourages architects to use BPS tools early and often in the design process to test design solutions to cost-effectively optimize performance beyond energy to improve occupant comfort and resilience[20]. In the author's experience, BPS tools enhance students' critical thinking, problem-solving, and environmental consciousness while fostering technological proficiency and adaptability to evolving technologies[21,22,23]. Their use instills resource-efficient design principles, while identifying competing metrics promotes a global perspective on sustainability challenges, and provides graduates with a competitive edge in the job market, making

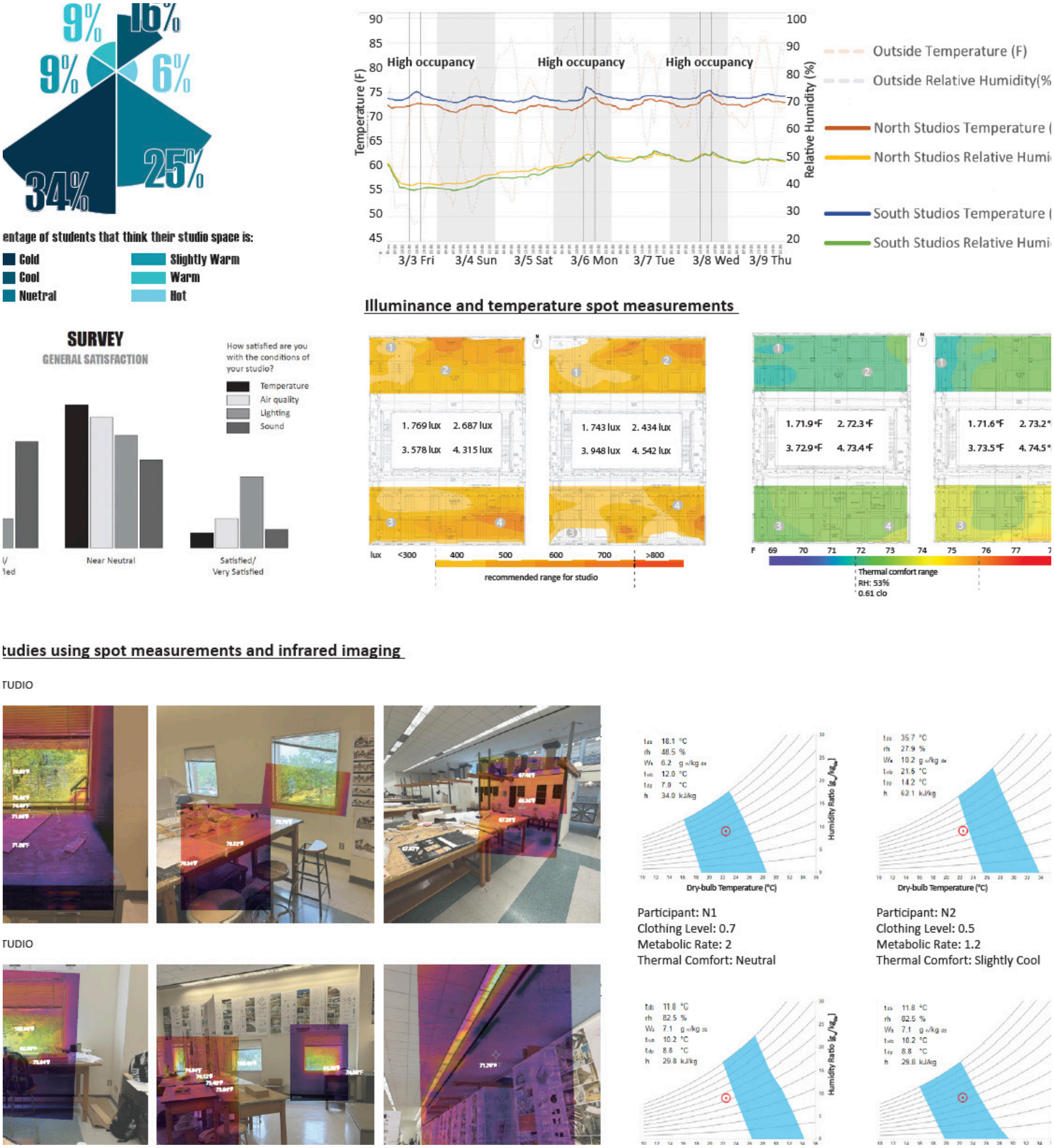
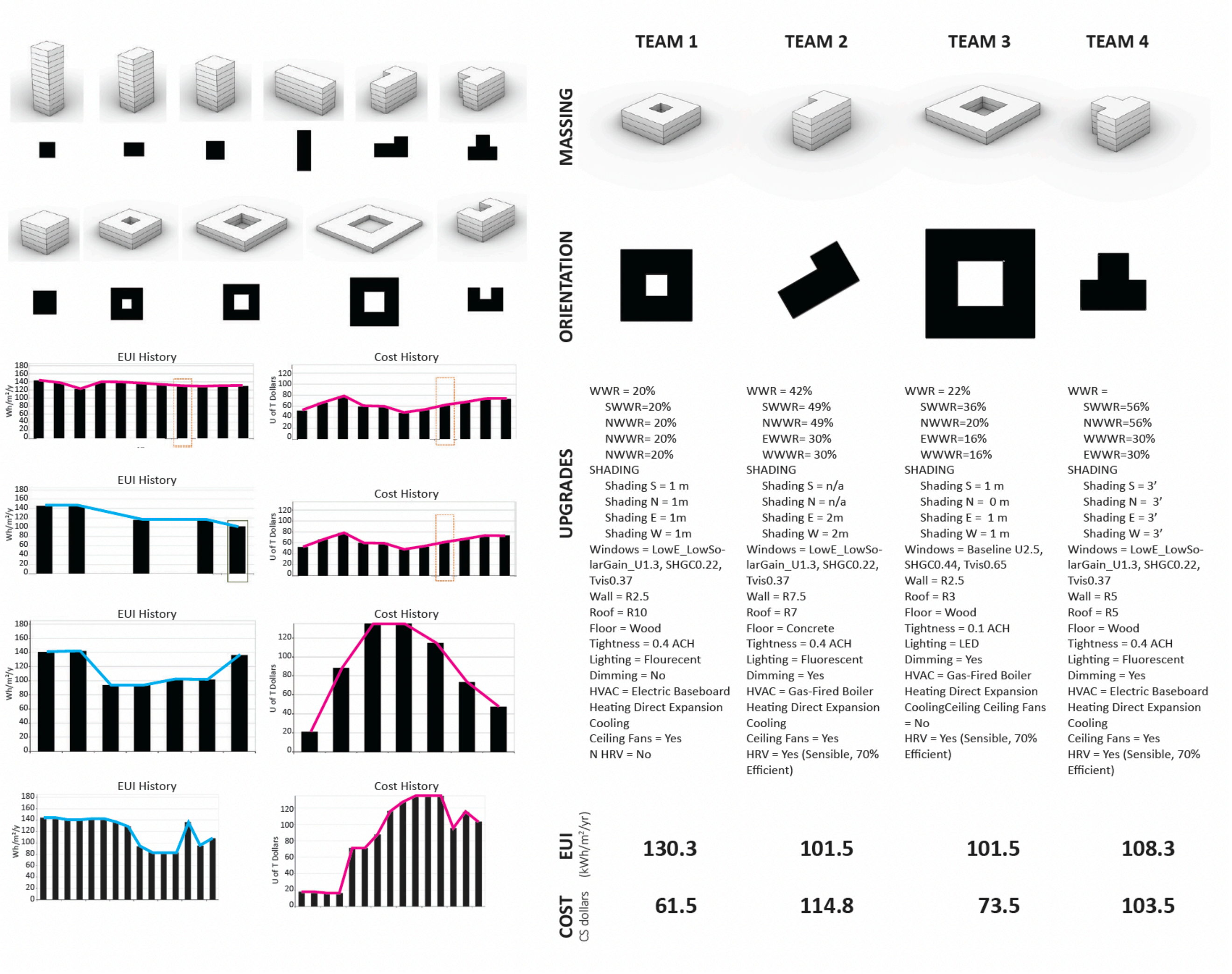


Figure 3. Examples of data collection and analysis during the post-occupancy evaluation project. Students study occupant comfort and satisfaction (occupant survey), thermal and visual patterns in spaces (spot measurements and datalogging), and human comfort (thermal imaging and interviews). Images taken or created by level 1 MArch students in May 2023.



	TEAM 1	TEAM 2	TEAM 3	TEAM 4
UPGRADES	WWR = 20% SWWR=20% NWWR= 20% NWWR= 20% NWWR=20% SHADING Shading S = 1 m Shading N = 1m Shading E = 1m Shading W = 1m Windows = LowE_LowSolarGain_U1.3, SHGC0.22, Tvis0.37 Wall = R2.5 Roof = R10 Floor = Wood Tightness = 0.4 ACH Lighting = Flourecent Dimming = No HVAC = Electric Baseboard Heating Direct Expansion Cooling Ceiling Fans = Yes N HRV = No	WWR = 42% SWWR= 49% NWWR= 49% EWWR= 30% WWWR= 30% SHADING Shading S = n/a Shading N = n/a Shading E = 2m Shading W = 2m Windows = LowE_LowSolarGain_U1.3, SHGC0.22, Tvis0.37 Wall = R7.5 Roof = R7 Floor = Concrete Tightness = 0.4 ACH Lighting = Fluorescent Dimming = Yes HVAC = Gas-Fired Boiler Heating Direct Expansion Cooling Ceiling Fans = Yes HRV = Yes (Sensible, 70% Efficient)	WWR = 22% SWWR=36% NWWR=20% EWWR=16% WWWR=16% SHADING Shading S = 1 m Shading N = 0 m Shading E = 1 m Shading W = 1 m Windows = Baseline U2.5, SHGC0.44, Tvis0.65 Wall = R2.5 Roof = R3 Floor = Wood Tightness = 0.1 ACH Lighting = LED Dimming = Yes HVAC = Gas-Fired Boiler Heating Direct Expansion CoolingCeiling Ceiling Fans = No HRV = Yes (Sensible, 70% Efficient)	WWR = SWWR=56% NWWR=56% WWWR=30% EWWR=30% SHADING Shading S = 3’ Shading N = 3’ Shading E = 3’ Shading W = 3’ Windows = LowE_LowSolarGain_U1.3, SHGC0.22, Tvis0.37 Wall = R5 Roof = R5 Floor = Wood Tightness = 0.4 ACH Lighting = Fluorescent Dimming = Yes HVAC = Electric Baseboard Heating Direct Expansion Cooling Ceiling Fans = Yes HRV = Yes (Sensible, 70% Efficient)
EUI (kWh/m²/yr)	130.3	101.5	101.5	108.3
COST CS dollars	61.5	114.8	73.5	103.5

Figure 4: Gamification in teaching. The Simulation Game[24] results using the Climate Studio plugin in Grasshopper, level 2 MArch - February 2021. Image by author.

it an invaluable educational resource.

Advancing to level 2, students are gradually introduced to computational simulation tools, experimenting with methodologies that allow them to integrate sustainable design thinking into their designs creatively. In Building Physics II, traditional lectures are replaced with short recorded videos covering fundamental theory, allowing in-class discussions and time to familiarize with the newly presented simulation tools. A variation of the Simulation Game, first presented by Christoph Reinhart in 2012[24], has been developed to introduce students to the notion and potential of computational simulations. In it, the students are tasked to try a finite number of strategy combinations, aiming for the lowest energy intensity with the lowest cost. The results are discussed in class not only as numerical achievements but also relative to the chosen methodology by each team (Figure 4). It has been observed, for example, that students begin with iterative tests of orientation, continue with sensitivity studies on window and shading sizing, and finish with a cumulative evaluation of additional strategies. In effect, this exercise introduces the students to the importance of performance studies and the difference between iterative, comparative, and cumulative effects of parameters.

Moving to Design Integration, the ET instructor is physically in the studio during selected workshop sessions, discussing projects one-on-one. In addition, ET and studio submittals are partially blended, impeding students from distinctly distinguishing between the two. The use of simulation tools is, at this point, significantly augmented. As students are heavily exposed to specialized architecturally oriented simulation tools, they are encouraged to understand and embrace the flaws in their design and the tools themselves. They ultimately appreciate the tools as mechanisms to inform educated assumptions rather than use them to fulfill absolute numerical requirements. While it is essential to keep up-to-date with the latest technological advancements in the profession, it is critical to do it without establishing a slavish relationship with the specific tools. The tools then are taught as the means to understand concepts and engage in processes creatively. In addition, utilizing such tools creates

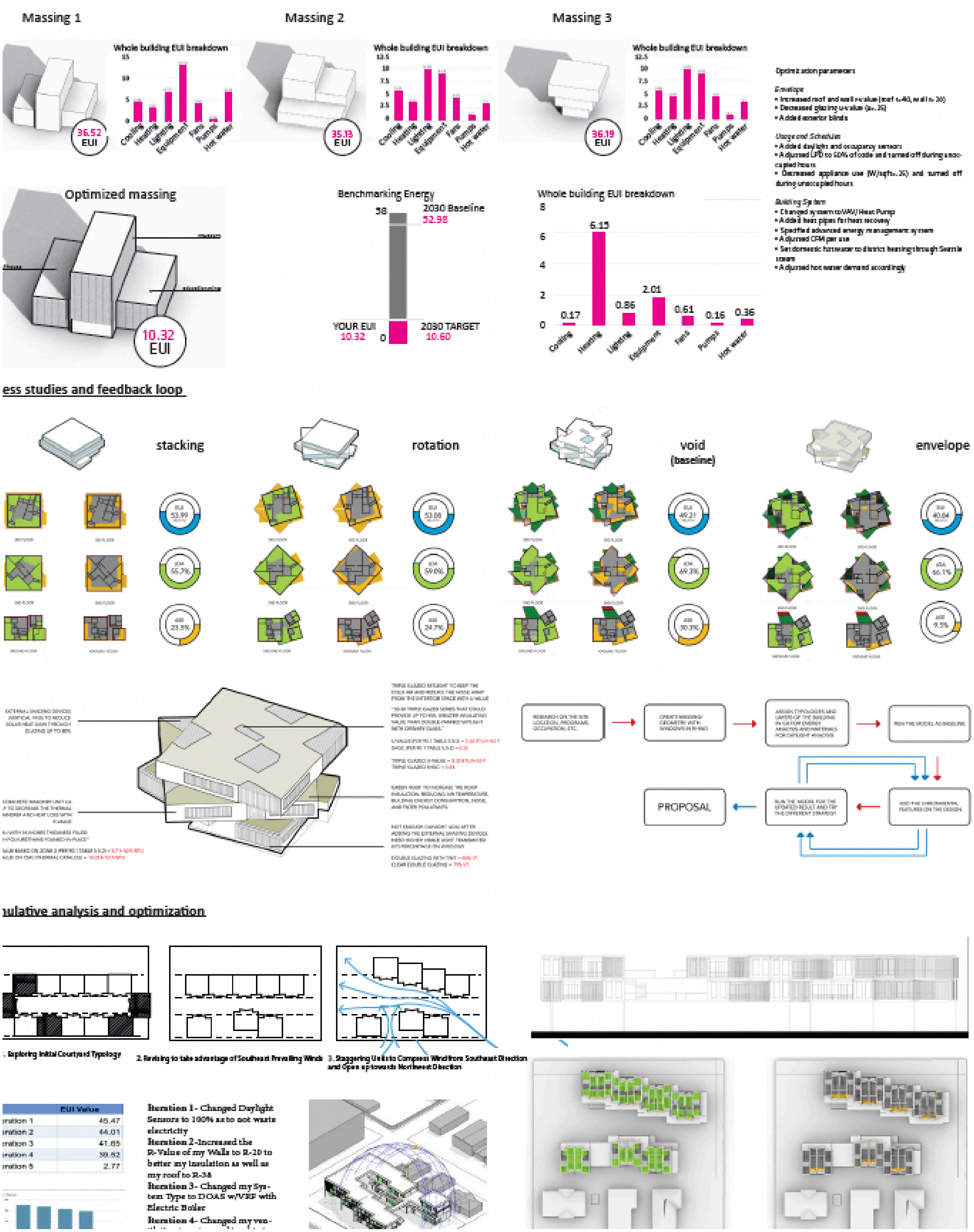


Figure 5. Student work examples practicing non-linear processes to inform their building designs. Top: Abraham Tavrin, May 2020. Middle: Siriko Naranphat, May 2021. Bottom: Alexander Archer, May 2023

the feeling that there is control over the environmental impact of each decision and forces the student to focus on the input parameters that affect each type of simulation. For example, the student chooses a glass type based on its U-Value and its solar heat gain coefficient (SHGC) for an energy simulation and based on its visible light transmittance (T_{vis}) for a (day)light simulation. This seemingly procedural detail, along with the ability to test the relative effect of each parameter, creates awareness of each design decision's effect on building performance and occupant experience. Students are encouraged to use analytical processes such as diagnostics and benchmarking, sensitivity studies, iterative and cumulative evaluations, fitness studies, and occasionally generative design related to energy efficiency, solar form finding, daylighting, wellness, and comfort. Figure 5 shows three student work examples using three methodologies to evaluate their projects: iterative analysis, fitness studies, and cumulative analysis, all leading to optimizing their designs while benchmarking using the 2030 Challenge. Like the POE exercise, the focus is on developing processes and methods. Evaluating early work is prioritized against the end product, and students learn to think and contextualize, not only to execute.

The curriculum structure presented in this paper has undergone a gradual transformation based on trial and error. Isolated methods and tools were first tested within the siloed ET courses, aiming for student engagement or buy-in that acted as the most effective advocate for the successful implementation. Infiltrating studio projects with theoretical frameworks and use of practical tools taught in ET classes was thus first introduced by students who felt more passionate about them and opened the way for the studio instructional faculty to seek more ways to welcome a more intentional integration. One important parameter that remains distinct between ET classes and studio projects is grading. This administrative parameter reinforces the division between the two and poses a unique obstacle to full integration. Navigating curricular mechanics and accreditation evaluations to merging grading efforts is deemed fundamental to the process, constituting a potential next step to this curricular development.

CONCLUSION

Architectural education is faced with a plethora of challenges, including the exponential development of climate change implications and the rapid advancements in technological innovation. The uncertainties those challenges pose relative to the speed of how humanity and architecture will react or adapt demand a renewed persistent focus on deep learning of fundamental theory and principles of sustainable architecture to safeguard adaptation and flexibility to encounter those uncertainties. At the same time, the profession is still confronted with persistent perceived dichotomies, such as the tension between its creative and technical nature. Given the imminent emergency of parallel climate crises in today's world, such dichotomies that create distinct silos in the profession must be transgressed to give way to more unified, flexible, and impactful design approaches. Finding pedagogical methods to unite analysis and synthesis effectively and without prejudice becomes imperative.

This article advocates the adoption of educational methodologies for graduate studies rooted in established pedagogical theories and informed by precedent educational paradigms that can respond to these two prominent aspects: 1) a "Post-Occupancy-Evaluation" (POE) project during a foundational level and 2) the use of "Building Performance Simulation" (BPS) tools during an intermediate level. In a highly computerized world and a profession bombarded by technological innovations, studying existing buildings offers the opportunity to return to the prime spatial and environmental understanding of the realities of architecture, including materials, scales, proportions, and human experience. In addition, integrating computational analytical tools into the design process is a competent tool to overcome the ongoing competition of prevalent constructed dichotomies in the profession, understand the complexity of design, and learn to think in interdisciplinary, flexible, non-linear processes. The two modules, as examples of field-learning and immersive-learning pathways, use learning-by-doing methods to nurture process-based mindsets that foster flexibility and adaptability to rapid changes. Consequently, this paper underscores the feasibility of implementing these methods in diverse educational settings, ultimately advocating for a universal implementation across all architectural curricula.

In paving the way for a more integrated and adaptable architectural education, these ideas serve as a foundation for further contemplation. As long as we use the term "sustainable environmental design" as separate from the universal term "design," there is work to be done toward scrutinizing such nomenclatures that full integration will no longer necessitate. To propel this discourse forward, it is crucial to question established norms and embrace a radical approach. Will architecture converge upon a prevailing style to meet these challenges? Can "sustainable design" attain a universally accepted definition within architectural education? Could architectural education emerge as the cornerstone for driving transformative change? While this paper refrains from delivering definitive answers to these inquiries, its aim is to explore practical tools that can facilitate the emergence of a more dynamic, adaptable, and conscientious architectural practice, ever-ready to address evolving societal and environmental demands.

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