# Learning Via Making, a Hands-On Approach

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ABSTRACT: *This paper showcases research and coursework conducted by the author in a higher education environment where hands-on approaches are used as the base for what is also known as experiential learning. The pedagogy is contextualized within the evolution of hands-on learning in academia, as well as the impact of new technology and advances in material sciences on learning through making. The goal is to understand how hands-on explorations in the use of concrete can constitute self-direct processes of conceptual and technical inquiry that can augment the students' self-critique to determine next steps in the design process, while acquiring a comprehensive understanding of the building tectonics.*

*Three methodologies are identified under experiential learning: design build, digital fabrication and scale prototyping. Through the use of course curriculum, the author presents case studies of each of these methodologies, as well as hybrid versions of their application. In all cases, knowledge production was advanced by making and testing as a framework for architectural discourse, enabling critical thinking in search of optimal solutions through hands-on explorations. Students gained new knowledge and skills by actively working on a specific problem or challenge while exploring broader and deeper realms of the course proposal through the prescribed material. When courses were combined with a project-based learning methodology, it enabled students to learn by actively engaging in real-word projects. Ultimately, knowledge production was advanced through engagement with industry leaders and demonstrated either in a design based on physical explorations and/or presentation of the proposal for a real client or audience.*

*Making is a unique resource able to critically inform the design process and provide real-time feedback. Therefore, it is expected that hands-on courses will expose students to the exploration of materials within conceptual and technical frameworks to legitimate design decisions. The presented courses demonstrate that these pedagogical models ultimately nurture students with an assertive and solid foundation that can propel them as creative thinkers in the architectural field. However, more research needs to be conducted on understanding the learning curve of students that experience the hands-on methodology over other types of learning and their impact on their post-academic work.*

KEYWORDS: hands-on pedagogy, design-build, digital fabrication, scale prototyping, concrete

## INTRODUCTION

John Dewey, a prominent American scholar, and a progressive educational reformer was one of the pioneers in the hands-on approach to education. He argued that this approach enabled the sense of reality acquired through first-hand contact with actualities. When referring to the importance of experimentation in children's education, he states,

> "[a]s to discipline, they get more training of attention, more power of interpretation, of drawing inferences, of acute observation and continuous reflection than if they were put to working out arbitrary problems simply for the sake of discipline" (Dewey, 1900).

Given the practical nature of the field, the pedagogy of many courses in architecture schools has traditionally included hands-on approaches. There are increased learning opportunities when hands-on exercises are strategically included in an architectural curriculum (Erdman, 2006). The very idea of designing through making is essential to grow and develop our practical knowledge through experience (Harrison, 1978).

Hands-on learning is a process that uses manipulation to deepen the understanding of the material possibilities and limitations while allowing an adequate response to specific needs. Hands-on courses constitute an excellent opportunity to explore and showcase innovation in materiality, including new applications of traditional materials as well as novel construction methods. Students can embrace emerging technologies and materials developing their "ethos of making" by critically experimenting with "the tectonic relationship of technology with technique and materials" (Wrightsman, 2006).

Over the last years, the author has been engaged in applied research in concrete in tandem with teaching a series of courses addressing experiential learning in the form of hand-on approach. Concrete is the most common man-made material on earth. Given its phase change from fluid to solid, concrete relies on formwork to adopt its final shape. The inextricable interdependence between concrete and formwork provides a fertile ground for exploration of the material itself, its formwork and casting methods. The casting process requires extensive hands-on experimentation and testing to understand the precise point of inflection between flexible fluidity and obstinate solidity (Mori, 2010).

The goal of this study is to validate learning through making as a comprehensive teaching methodology that provides students with a robust understanding of building tectonics. It also aims to demonstrate how the exposure of students to direct experimentation with materials within conceptual and technical frameworks could legitimate design decisions while increasing the knowledge production in the classroom.

## 1. HISTORIC OVERVIEW OF HANDS-ON LEARNING IN ARCHITECTURE EDUCATION

Architecture, like engineering, is a practical discipline where design, making, and serving humankind is its fundamental purpose (Feisel & Rosa, 2005). Making things is a rational activity that has the potential of changing the world by bringing into existence objects and entities that did not exist before (Harrison, 1978). Both professions, before becoming part of academia, were rooted in apprenticeship methods where design, analysis, and manufacturing of creations took place – in other words, they were disciplines rooted in the notion of learning by doing (Feisel & Rosa, 2005). However, the academic system did not emerge to substitute the apprenticeship system. In the case of architecture education, the initial goal was to incorporate theoretical discussions about art and architecture and to develop the drawings as a medium to conceive buildings beforehand (Celani, 2012). During the Renaissance, drawings became a truthful depiction of the three-dimensional world, introducing a fundamental change in perception; consequently, architects gained a much higher status given their role as drawing makers (Hill, 2005). Making drawings became as important as making buildings; the two acts fused into an inextricable relationship. It was not until the early twentieth century, that the framework of a workshop-based academy was implemented in the inception of the Bauhaus in Weimar in 1919. Bauhaus's founder Walter Gropius, was the youngest of the Deutsche Werkbund's leaders. He envisioned reconciling art and an industrialized society, a problem that William Morris had foreshadowed in the 1880s in reaction to the artistic confusion of his day. Gropius wanted to combine the Academy with the Weimar Arts and Crafts School to create a "consulting art center for industry and the trades" (Dorner, 1975). Therefore, the Bauhaus was founded as an institution in flux promoting new methods of instruction in the visual arts while challenging existing academic practices (James-Chakraborty, 2006). Conception and materialization of objects were no longer considered two differentiated tasks. As the first proclamation of the Weimar Bauhaus states, "There is no essential difference between the artist and the craftsman" (Bayer, 1975). In October 1920, the Council of Masters approved a reform to increase the workshop training to six hours a day. The technical drawing was also introduced by Walter Gropius who taught theory and Adolf Meyer who introduced the practical side of the subject. The objective was to integrate the theoretical background of teaching with practical workshop training. This "bipolar" teaching model enabled students to receive a comprehensive education where apprentices had two mentors: a Master of Forms and a Master of Craft (Droste, 2006). Pottery, textile, metal, furniture, stain glass, mural-painting, wood carving, stone sculpture, bookbinding, and graphic printing were some of the workshops offered. However, despite Gropius's intention to place architecture as the central discipline of the Bauhaus curriculum, a workshop for architecture was never offered. Instead, Gropius gave students practical hands-on learning experiences on an experimental building site and apprenticeships in his office (Miller, 2006). Gropius's explanation of the culminating phase of the Bauhaus curriculum was described in his essay "Idee und Aufbau des Statliches Bauhauses Weimar" in which he establishes that journeymen are drawn into formal and manual collaboration in actual building projects so that, through practical experience, they would become acquainted with all of the building trades (Dearstyne, 1986). Gropius intended to merge art and technology into a new discipline coupled with the possibilities provided by the industrial production to deliver objects that were functional, aesthetic, and able to comply with industry standards (Garmazio, Kohler & Oesterle, 2010). Although Gropius was a strong advocate of handwork, he was very aware of the advantages of machine production and embraced the idea of having factories at the disposal of the creative artist to develop new forms; he envisioned art and technology as a new unity (Dearstyne, 1986). Despite the Bauhaus's strong influence on architectural education, after World War II many professional schools were incorporated into larger universities and gradually changed the curriculum to include more scientific content, losing part of their traditional hands-on educational methods. As science and technology rapidly advanced, architectural education reduced its practical instruction into the "science laboratory" to conduct tests of physical concepts in architectural applications such as wind, acoustics, and light studies. In the 2000s, the advancement in digital technologies resulted in the introduction of computers in architectural schools' model shop in. Digital fabrication labs enabled systematization, use of control variables, elaboration of conjectures, and documentation of processes of experimental work that characterizes the scientific approach in education (Celani, 2012).

### 1.1 Material Explorations and the Hands-on Approach

Although architecture and material are intrinsically intertwined, in general materials receive superficial attention in architectural design. Form, structure, and geometry have dominated architectural discourse, leaving materiality unattended (Borden, 2018). Through a methodology of research and experimentation, material explorations can advance the projects, which can, in turn, benefit from informed decisions based on the capabilities and limitations of different construction materials, the applied construction methods, and their performance. Moreover, materiality has become a field of study that opens up an enormous range of possibilities for buildings and ultimately, the user. Technical innovations emerge from accepted procedures of science-based engineering and creative thought (Fernandez, 2005). In academia, design studios typically focus on the spatial quality and configuration of the projects, while oftentimes material selection is not necessarily a part of the studio agenda. Yet, building materials, their inherent properties, and assemblies are key in defining buildings' space as well as the identity of buildings themselves. Hence, materiality should be an integral part of the design process from the early stages of education. This has a particular impact on students as the act of manipulating materials subconsciously develops the ability to interpret the possibilities and limitations of materials and assemblies during the design process (Oakley, 2007).

Material is the medium of architecture; its intrinsic qualities and limitations, manufacturing processes, and formal capabilities determine the approach to design and form (Borden, 2010). Consequently, material is essential to form. Therefore, the production of objects and their associative qualities are intertwined with the material, its tools, and processes of production (Borden, 2018). Materials impose constraints not only on what is intended to build but on the understanding of construction as a finished product (Harrison, 1978).

Meanwhile, buildings and their constituent elements are in constant evolution. Advances and discoveries in material and fabrication technologies can have a strong influence on the way buildings are made (Rowe, 1987). Therefore, architecture is susceptible to changes in the very material and dimensional aspects that fundamentally determine its constitution. Using contemporary materials in the best possible ways involves a technical understanding as well as design invention (Fernandez, 2006). In their book, *Morpho-Ecologies,* Hensel & Menges introduce the term *material system* as an integral concept that describes the complex reciprocity between materiality, form, structure, and space, including the related processes of production and assembly, and the performative effects derived from the interaction with environmental conditions. Architecture is characterized by prioritizing form generation over inherent material logic. As a result, means of materialization, production, and construction are executed as top-down engineered material solutions after the building shape is defined. Usually, the materialization of these designs pays little to no attention to functionality and performance (Hensel & Menges, 2008). *Digital morphogenesis* refers to the processes of form generation resulting in geometries detached from material and construction logic. *Natural morphogenesis*, on the other hand, is a process of growth and evolutionary development that generates systems capable of obtaining complex articulation, specific gestalt, and performative capacity through the interaction of system-intrinsic material characteristics and external environmental forces and factors. Therefore, materialization and design are inextricably related to natural morphogenesis, where form generation and materialization processes are part of one undifferentiated process that enables morphological complexity and performative capacity (Menges & Ahlquist, 2011). This is especially pertinent in the design and construction of buildings using digital technology where material and morphological characteristics are derived through iterative feedback loops by continually processing the material system's interaction with statics, thermodynamics, acoustics, light, winds, and others (Hensel, 2010). While the predominant approach in architectural schools consists of using digital technology for formal explorations without consideration of construction, the notion of *material systems* emerges as a generative driver in the design process (Hensel & Menges, 2008).

## 2. HANDS-ON COURSES USING CONCRETE

Concrete has a reputation as a not sustainable material. Cement production accounts for an estimated 1.2 percent of U.S. greenhouse gas (GHG) emissions and 7 percent of global carbon emissions (Fransen, 2021). While, it is the cement the component that has a high carbon footprint, it only accounts for about 10% of the concrete mix. Besides steel used for reinforcing, the other components of concrete –water, sand and coarse aggregates- are fairly low in carbon emissions. Today, there are a number of approaches to reduce the carbon footprint of concrete and reduce the usage of cement including adding inter-ground limestone to Portland cement, improving aggregate gradations, incorporating supplementary cementing materials, using recycled concrete aggregate, injecting CO2, employing water-reducing admixtures, and other methods. However, the quality that distinguishes concrete from other construction materials from a sustainable point of view, is its inherent durability and resiliency. Concrete outperforms all other common construction materials with a much longer lifespan and can be employed as both part of the structure and the envelope of buildings. It requires no maintenance and, if properly insulated coupled with its inherent thermal mass it works as a very efficient thermal envelope and ultimately, an outstanding overall life cycle performance. Ranging from speculative and conceptual exercises to project-based learning, these hands-on laboratories ultimately tested the effectiveness of the pedagogical model experiential learning in delivering feasible solutions to architectural proposals using concrete.

### 2.1 Design Build

Design-build is a pedagogical alternative to desk-oriented and media-based design processes typically adopted by design schools, in which students engage in both the design and construction of projects (Canizaro, 2012). Design-build education has its origins in the late nineteen century and its goal still prevails as conjoining design with the act of building as a single process (Verderber, 2014). Students actively participate in practical exercises aimed to develop their sensibilities about all aspects of materials and how they are used in the built environment (Erdman, 2006). The primary goal of a hands-on curriculum is not only the acquisition of knowledge about material and construction but also learning delivery methods and budgeting, increasing exposure to other cultures and history of specific regions, and engaging in community service among other opportunities (Erdman, 2006). There is a long list of schools across the country that have embraced some kind of design-build project and a shorter list of schools that have consistently taught these kinds of courses for long periods of time. The curricula usually deliver full-scale projects that can range from simple structures such as pavilions to more complex ones such as single-family houses. Usually, the students are challenged to expand their design skills by experimenting with real construction tasks putting together different materials and assemblies, and using the appropriate tools. During this process, the outcomes evolve through the act of making rather than as a result of the execution of a design strategy (Sheil, 2005). Students learn by building. In short, design-build education is a design activity that enriches the students' decision-making through direct engagement and ultimately exposes students to a broader range of architectural practices (Canizaro, 2012). If we put into perspective the challenges that most students will face after graduating, there is no doubt that the experience gained in a design-build project serves as an introduction to the design hurdles and inquiries present in the professional realm.

### 2.1.1 Surface_It, with Pieces (Elective Seminar)

These hands-on labs consist of two fabrication seminars offered in the fall of 2011 and 2012. Students were asked to design and produce a set of repeatable concrete units to generate a man-made topography (hardscape) capable of modifying physical interaction with the ground.

The design exercise started by exploring pattern options and tessellations, based on the repetition of a specific geometry, which resulted in the design of one or more pieces. The pieces were developed with consideration of the limitations of the material in terms of strength, weight, and size, among others in order to be handled by a single person. Students built the corresponding molds and cast concrete to produce pavers (Fig. 1).

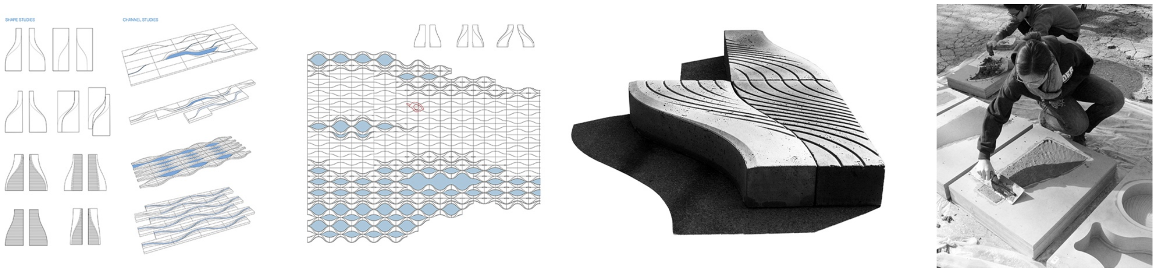

Figure 1. Surface_It,with Pieces F22. Concrete pavers designed and manufactured by students. (Photographs by author)

In these seminars, students gained practical knowledge about the act of construction, assemblage and mass production, as well as the use of digital and analog tools, the basics of mold making, and other fabrication techniques while testing their abilities to design a prototype to create walkable surfaces. Concrete colors and surface treatments such as textures and exposed aggregates were also subject of study.

One of the limitations factors of this course was the lack of funding. Students had to purchase their own materials. Most of the molds relied on the use of urethane rubber which although it allows multiple castings, it was very expensive and limited the size and quantity of molds produced. In some cases students had to produced single cast molds which were time-consuming to make and only yielding one cast. However, they provided tangible outcomes allowing students to assess the capabilities of small molds for concrete production.

### 2.1.2. Furnish_It, with Pieces (Elective Seminar)

Funded by Anova, a local urban furniture company, the projected-based seminar was offered for five consecutive semesters, in the fall 2013, 2014, 2015, as well as spring 2017, and 2018. This new pedagogic agenda challenged students to research specific materials – including concrete, metal, recycled plastic lumber, and lamboo (laminated bamboo) – to design and implement methods of construction to build usable urban furniture. Different concrete types and formwork techniques were employed based on the geometry and size of the pieces. Standard concrete and Glass Fiber Reinforced Concrete (GFRC) mixes with different types of fiberglass reinforcing were tested. While prototyping the furniture, students were asked to take careful consideration of human scale and ergonomics.

The fabrication courses served as valuable learning experiences for the students while increasing the school's capacity to effectively manage, promote, and implement the use of digital and analog fabrication tools to deliver design-build projects. Students received feedback on the design and technical intricacies of their projects from designers and manufacturing experts from the company. Such interaction greatly benefited the students' understanding of the fabrication process as well as the outcome of the final product. The furniture produced during the first two semesters were installed in a vacant plot turned into a naturescaping in the Old North St. Louis neighborhood, providing its residents useful and much needed outdoor furniture. All the projects consisted of assembled pieces challenging students to design, coordinate and execute feasible connections. Having a sponsor involved and end users for the final product not only made possible more ambitious projects but also created a sense of accountability on students that empowered and incentivized the production process (Fig. 2).

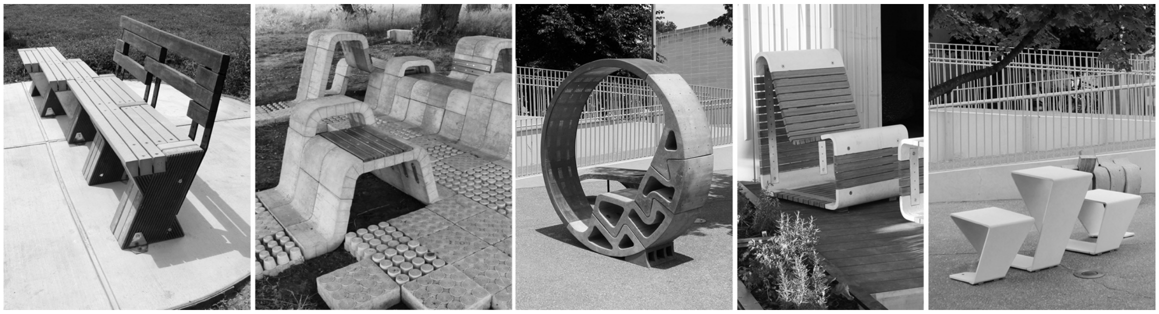

Figure 2. *Furnish_It,with Pieces*. Urban furniture designed and manufactured by students. (Photographs by author).

### 2.1.3. CRETE House, Solar Decathlon 2017 (Design Option Studios)

This initial hands-on, small-scale teaching experience was followed by the author's participation as the Faculty Project Design Leader in Washington University's Solar Decathlon 2017 competition team. For this project, the school collaborated with several precast partners. This was a two-and-a-half-year commitment culminating in the construction of the CRETE House, a model for advanced building technology, resiliency, and livability (Fig. 3). CRETE house achieved second place in the Architecture Contest (Moyano Fernandez, 2020).

Figure 3. *CRETE House* in Denver, CO. Solar Decathlon 2017 (Photographs by Richard Nodle).

The nature of the competition called for the project to be conceived and materialized in a non-conventional construction method. The house was designed as a demonstration of integrated advanced building technology to show how precast concrete homes can be a compelling alternative to traditional wood light-frame construction, providing a strong (tornado resistant), resilient, durable, and maintenance-free envelopes. Thin shell exterior walls were manufactured using Ultra-High-Performance-Concrete (UHPC), a fairly new material with exceptional mechanical properties and an innovative alternative for building envelopes. Students participated in the entire process, including the early stages of research and design, design development, documentation, and construction. Students also actively interacted with industry partners and manufacturers involved during the design, fabrication and assembly processes gaining invaluable experience. The grooving on the surface of the exterior UHPC wythe was done by students using formliners that were reutilized in different orientations for multiple casts as master molds to achieve a non-repetitive appearance. Students spent an entire semester designing and producing molds made in MDF using a combination of hand-made and CNC equipment and then cast formliners out of urethane rubber. (Fig. 4).

Figure 4. CRETE House. Formliners fabrication process led by students (Photographs by author).

The students that participated in the project later reported very positive feedback highlighting how their learning experience eventually marked their trajectories as professionals. In particular, the dual degree students pursuing MArch and MCM (Master of Construction Management) were able to take full advantage of the project by participating in the different design phases through studios and supporting electives, as well as by taking key roles in critical tasks during the construction phase.

## 2.1 Digital Fabrication

With the emergence of digital fabrication technologies, architecture and the construction industry in general greatly expanded their options in terms of the materialization of building assemblies. The introduction of computer-aided-design (CAD), and computer-aided-manufacturing (CAM) established a robust digital platform nurturing designers with new sets of tools while enabling an expansion of their creativity and sophistication – and sometimes, the performance– of building components. CNC and 3D printing are examples of technologies that helped advance the construction of innovative assembly methods. These tools also have the capability of materializing sophisticated geometries, providing designers with a broad spectrum of morphological possibilities, embracing the mass production of differentiated building elements. As the Industrial Revolution embraced repetition and mass production, the Digital Age is giving way to singularity and mass customization. Yet, the departure from the economics associated with orthogonal geometry tectonics requires more precision from the interface between architectural form and the computer-driven fabrication processes (Weinstock, 2011). The traditional design process started with the definition of the form by the architect followed by the definition of the structure and material in collaboration with engineers (Celani, 2012). The rise of digital fabrication technologies in architecture not only expanded the designer's options when it came to building design and construction but also pushed design and construction into a new direction. As a result, this marked a cultural evolution in the design and construction of buildings, where expanded collaborative relationships between architects, engineers, and oftentimes professionals from other disciplines are rapidly becoming the norm. The traditional sequential development of form, structure, and material was challenged by the cultural shift. In the words of Rivka and Robert Oxman (2010), a new order called The New Structuralism rose. Innovative materials, production methods, and technologies directly inform architectural construction (Barkow, 2010). Architects can integrate fabrication as a generative paradigm into the design process (Garmazio, Kohler & Oesterle, 2010). The New Structuralism sequential process was redefined as material, structure, and form (Oxman & Oxman, 2010). Leading architecture schools rapidly adopted digital technologies in the late 1990s. The physical manifestation of this was the introduction of dedicated space for digital fabrication laboratories (Celani, 2012). The implementation of digitally fabricated projects in schools was present both in full-scale and scaled-down options. Today, the prevalence of digital fabrication in most architectural schools has opened up a broad spectrum of possibilities in building technology and design that is reluctantly being adopted by the construction industry. While digital fabrication tools can offer appealing construction methods, these methods usually rely on a labor-intensive process to set up the equipment, assemble the components, and finish the piece. Consequently, there is still a wide gap between the assemblage process required by digital technologies and the methodologies effectively adopted by the building industry.

### 2.2.1. Precast Concrete Enclosures (Elective Seminar)

This design-build elective, was offered in the spring of 2021, 2022 and 2023. The seminar was based on the design and fabrication of full-scale (1:1) precast concrete building envelopes. Due to the size and weight of the panels, the materialization of full-scale prototypes required collaboration with industry partners as it provided access to resources not generally available at higher education institutions. With this in mind, a partnership was established with Gate Precast company and supported by a PCI Foundation grant. The pedagogy of this seminar exposed students to different precast methodologies and best industry practices through the design-build agenda. Therefore, the fabrication of concrete building enclosures highly benefitted from the partnership through the novel applications of concrete and associated products, the understanding of precast manufacturing practices as well as construction systems. During the process of making full-scale formwork, students were engaged in direct experimentation, learning about the properties of the materials, the act of construction, assemblage, and mass production. Important topics such as panel size, thickness, structural integrity, reinforcing, connections, and resistance to the weight and pressure of fresh concrete, among others, enable students to learn from the precast manufacturers' expertise. Students' proposals were assessed by engineers and plant personnel from Gate Precast in person and online; their feedback was critical to advancing their design to a feasible outcome. Students were able to experience the entire design-build pedagogical model including research, design, experimentation, documentation, and materialization of full-scale molds and concrete panels. Full-scale formworks were materialized at school using both analog methods and digital fabrication tools. Digital fabrication tools have the capability of materializing sophisticated, non-conventional geometries providing students with a broad spectrum of morphological possibilities as part of building envelopes. The molds were transported to the manufacturing facility in Ashland City, TN for concrete casting. A field trip to the plant allowed students to witness the casting and actively participate in the demolding of the panels.

Gate's plant personnel were very impressed with the quality and complexity of the molds the students made. Architects and contractors from all over the country visit the plant regularly and find the panels produced by this course very helpful to understand the design capabilities subjacent in precast concrete envelopes. Students learned about the fundamentals and intricacies of the precast process and carefully observed and documented the entire process through photographs and videos. The experience gained in fabrication courses like this one serves as an introduction to the design inquiries, possibilities and challenges that students will soon face in the professional realm, equipping them with a one of a kind experience (Fig. 5).

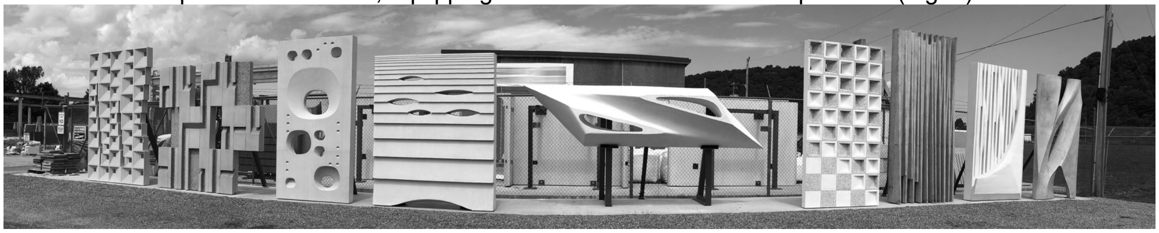

Figure 5. *Precast Concrete Enclosures*. SP21 & SP22 Full-scale panels designed and made by students on display at Gate Precast plant in Ashland City, TN. (Photograph by Daniel Thomson).

## 2.2 Scale Prototyping

Prototyping is essentially the production of something new as compared with previous models. The strength of the prototype as a working methodology is that it supersedes representational strategies (drawings and scale models) with an artifact that predicts with a high level of accuracy the architectural effect and its performance. The built prototype is an actual constructed object serving as an effective means to close the gap between representation and actual building (Barkow, 2010). Size is usually a limiting factor when it comes to the production and storage of prototypes. Prototyping can be implemented at full scale or a range of smaller scales allowing faster and more economical approaches to fabricating and testing samples.

Designing by making takes observation to a greater intellectual involvement with the developing product. During the creative process, the model outperforms drawings (Porter & Neale, 2000). The act of making reinforces the understanding of three-dimensional space where the physical models offer a continuum in the perceptual and design generative process (Lee, 2015). The reason why architectural physical models are so important in the design of buildings is that they are considered the most effective way to understand spatial quality and they bring into play various other faculties of judgment including binocular vision, allowing a wider field of view and a precise depth perception (Prizeman, 2005). Three-dimensional scaled models have served for a long time a very common design and representation tool in architectural offices as well as in architecture schools. Physical models vary in scale and scope. Models either at 1:1 or scaled prototypes, can operate as functional models carrying behavioral aspects of the intended assemblies. The construction of an artifact demands understanding and interpretation and is a vehicle for thought (Harrison, 1978). They are excellent instruments for form-finding, topological coherency, performance capacity analysis function, manufacturing, and assembly method investigations (Hensel & Menges, 2006).

### 2.3.1. Resilient Concrete Undergraduate Option Studio SP22

Current construction practices for single-family residential buildings in the US use predominantly wood frame, ninety percent of homes built in 2019 were wood-framed, according to the National Association of Home Builders. Despite its benefits, wood structures face several challenges such as combustibility, susceptibility to degradation by humidity, mold, and insect infestation, and its inherent vulnerability to withstand debris impact in case of extreme weather events, such as tornadoes, regardless of the cladding system selected. Alternatively, concrete construction can provide buildings with robust structures and envelopes with a longer lifespan compared to other traditional methods. During this studio, students were asked to use concrete as the primary constituent material in the design of a small resilient house located in a rural area within a tornado alley zone in the mid-west. With a focus on the design of the building envelope, and considering the bearing and resilient capacity of concrete, this studio challenged students to envision ways to design strong concrete shells able to withstand extreme storm forces. Concrete construction offers strong and durable building envelopes that are maintenance-free. Special emphasis was placed on learning through making while seeking the simultaneous use of intuitive explorations with feasible outcomes of concrete design principles. Hands-on sessions were dedicated to exploring different techniques of formwork making and concrete cast to acquaint students with concrete, in particular, how materiality determines the way buildings are made and perform. The overarching inquiry of the studio was how material and concrete tectonics can define a working conceptual framework to generate buildings. The studio was structured in three correlated assignments. In the first phase, students investigated how different configurations of a building envelope could protect the interior space from severe weather conditions allowing the controlled passage of light and air. This assignment required envisioning a building envelope for a single space. Using a virtual cube of 12' x 12' x 12' as a point of departure, they were asked to designate two sides of the volume as part of the exterior envelope. This enclosure had to include at least one opening to allow light and air into the space with careful consideration of its size, purpose, orientation, and experience from inside-out and outside-in. This process provided the basis of a design framework to be further developed as a strategy for the conceptual understanding of a building envelope and the basis for the casting methodology for the next assignment (Fig. 6).

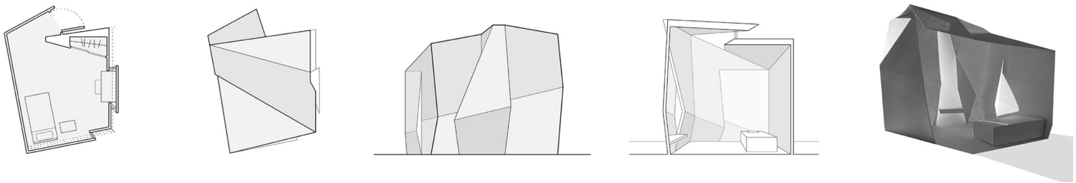

Figure 6. *Resilient Concrete Studio* SP22, Assignment 1, Exterior envelope study. 1”=1’-0” scale prototype. Student: Maya Yildirim

During the second phase students were asked to materialize the anatomy of the envelope developed in the previous assignment in concrete. Students were introduced to Sequential Casting Concrete System (SCCS), a casting technique developed by the author (Moyano Fernandez, 2021). This hands-on approach, allowed students to investigate and design within the possibilities and limitations of this casting methodology while incorporating highly creative and digitally fabricated geometries, details, and textures (Fig. 7).

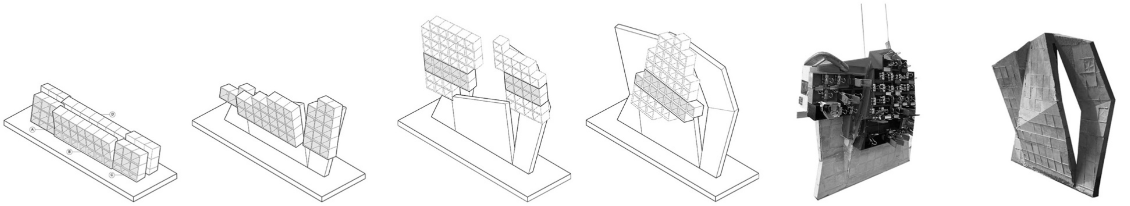

Figure 7. *Resilient Concrete Studio* SP22, Assignment 2, Sequential Casting Concrete System. 1”=1’-0” scale prototype. Student: Maya Yildirim

Through experimentation with actual concrete mixes and molds, students were able to elucidate the essence of the material, its properties, and its architectural applications. SCCS was used as a generative driver that integrates materiality as a medium for form-finding in performative concrete envelopes. As a first step, they adapted the design by developing a series of small and reusable molds to cast the concrete in sequential steps. Students worked on scaled prototypes at 1”=1’-0” scale in concrete. The methodology called for in-depth research through direct experimentation, challenging students to rethink the materialization of traditional enclosure solutions and testing ideas through an iterative process. Making scaled prototypes in concrete is a vehicle for students to explore the use, characteristics, and potential of building materials, their assembly, tectonics, and, ultimately, spatial configurations (Canizaro, 2012). The third and last phase was dedicated to the design of a 1,200 sq. ft. house in a rural site. The conceptual ideas developed in the previous two phases provided the design framework for the house. Therefore, the programmatic components were expected to be integrated with the emergent tectonic logic into a single robust massing to safely protect its dwellers from severe weather conditions (Fig. 8).

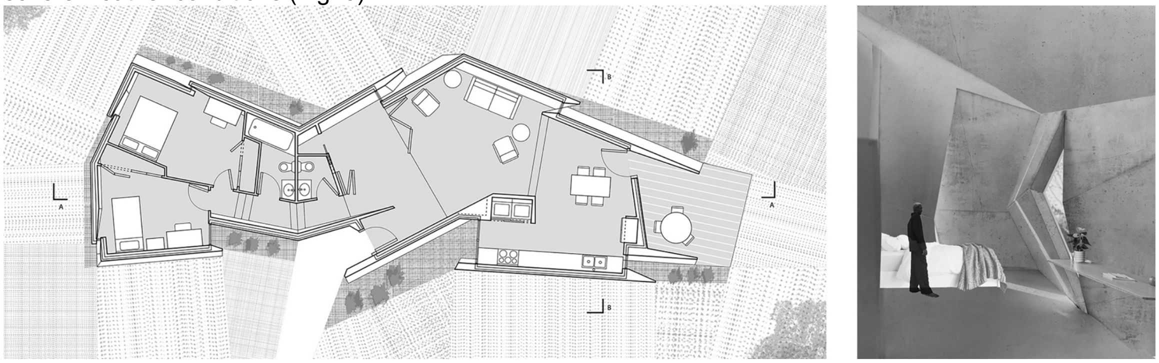

Figure 8. *Resilient Concrete Studio* SP22, Assignment 3, Design a resilient concrete home. Floor plan and interior view. Student: Maya Yildirim

The sequence of exercises was intended to prompt students to research, make, and design simultaneously. The studio pedagogic based on material experimentation allowed students to make informed and responsive design decisions grounded in the logic of the material and methods of construction. By the end of the semester, students were able to critically engage a conceptual idea through the design process by experimenting with a specific concrete formwork technique to inform the tectonics possibilities of the concrete (Fig. 9).

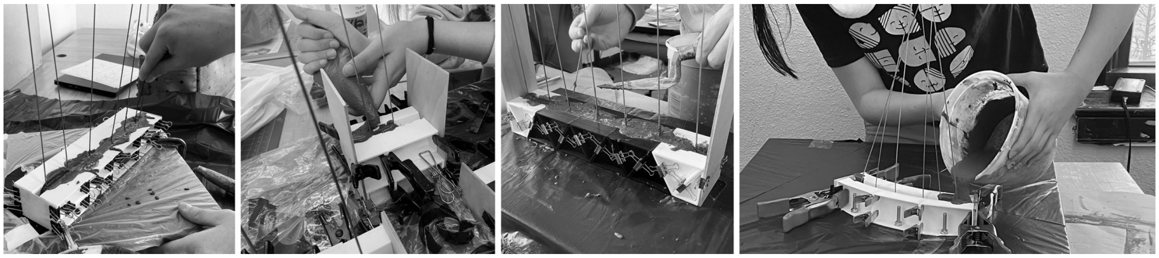

Figure 9. Students casting prototypes using *SCCS* method developed by the author. (Photographs by author).

## CONCLUSION

The realization of ideas into built form is a necessary step during which some qualities are gained and others are lost. As immaterial and intangible ideas develop, the question of how things are made generates a period of opportunity (Sheil, 2005). Hands-on learning highly benefits students to develop an intrinsic understanding of how things are made. Yet, in most architecture schools across the US, the hands-on approach as a pedagogical model tends to be limited to specific studios and seminars where the curriculum relates to materials and methods of construction, not as a holistic approach to architectural education.

Due to the rapidly ever-evolving material science and computer technologies that support both the design and construction of buildings, it is key for educators to provide students with fundamental principles of building technology that remain present regardless of time as core concepts of building tectonics. When the conceptual framework of a project is rooted in the act of building rather than theoretical notions of divergent topics, architectural design becomes deeper, richer, and physical, in other words, real (Oakley, 2007). The constitutive material of any built form determines its morphological potential and limitations while serving as the media with which designers can operate. The invention and use of new materials and the re-interpretation of traditional ones have been at the root of architectural evolution (Borden, 2018). Hands-on education constitutes a pedagogical method that uses materialization as the way to allow the imagination of the designer and the act of execution to be the vehicle of inquiry and invention. The exercise of design via a hands-on approach provides students with a set of technical skills, a fundamental tectonic foundation particularly important in buildings design and construction. By working at full-scale, the appreciation of the size and the limits of material manipulation became decisive aids to furthering architecture beyond the mere discussion of form and intellectual process (Prizeman, 2005).

Interestingly, this was evident in both full-scale and scaled prototypes courses presented. Although full-scale approaches gave students a very realistic exposure to the constraints and possibilities of the real building components, its execution was usually more challenging primarily because of the size, weight, time, material resources, and budget demands. Scaled prototype experimentation in concrete provided students a very similar experience than full-scale counterparts and allowed the execution of entire assemblies without the constraints and limitations of larger full-scale pieces. Students making concrete prototypes at 1”=1’-0” scale were able to test their initial envelope concepts with a specific casting methodology achieving a high level of accuracy and control. Making is a resource that critically informed the design process and provided real-time feedback. Mistakes and/or miscalculations were addressed and corrected in further testing, while self-directing the steps in the design process.

In sum, hands-on courses exposed students to the tactile exploration of materials within conceptual and technical frameworks while legitimated design decisions as they gained a deeper understanding of building tectonics. The act of learning via making became the guiding principle of the design process. Ultimately, the hands-on model nurtured students with an assertive and solid foundation that could propel them as leaders in the architectural field. Although there is substantial evidence that architectural schools can greatly benefit from experiential learning, for experiential learning to become the predominant pedagogic model in architecture education, a comprehensive evaluation would be required. Further assessment should be done on students taking hands-on courses to determine the short-term effect on the impact of this pedagogy on their academic leaning as well as the long-term effect of experiential learning on their post-academic careers.

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