Pedagogy at Full-Scale

This paper considers the value of full-scale prototyping in architectural education, and outlines an alternative model of pedagogy that utilizes prototyping exercises, as a type of design research, to cultivate material agency in studio projects.

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Initially formulated in response to an increasing absence of material intentions, material performance, and spatial atmosphere in academic projects, this pedagogy elevates material matters to the top of a studio's discourse on design. "Pedagogy at Full-Scale" takes a position on several fundamental questions. When in the design-process should material systems be considered? Are research and practice distinct endeavors, or can these two modes be folded into a singular or synthetic design-process? While isolated research in workshops might yield faster and/or better local results, its seclusion from a project has a limiting effect on its ability to integrate into a student's project-based design-process. Influencing this process is critical, since most students will work on the design and realization of buildings following graduation. By considering material systems at the beginning of the design-process and utilizing full-scale prototyping as a mechanism to further conceptual or design development of material systems, the two modes of research and practice can merge into a fluid project-based design-process with material specificity ever-present and embedded in the generative instructions of a project.

As an instructional tool towards achieving a desired learned outcome, full-scale exercises can be developed, instituted, and its results measured, as one normally would do for any other tool. However, their atypical size and medium requires special attention in planning and resources that are not usually allotted for including: physical space for staging, access to necessary equipment for fabrication, and monetary funds. Surprisingly, the exercises do not require prior fabrication experience or skills to achieve desired results and can even be deployed within a foundation level course. This paper will address some common questions regarding their value and implementation. What specific lessons are learned through full-scale exercises? What are their critical limits? What is their impact or influence on the development of larger-sized projects?

To explicate the pedagogy, one recent studio course will be examined in detail. The foundation level course is structured to allow a deep investigation into two material systems: one focused on structure and the other envelope. Students are assigned two material systems, and through a precedent analysis, asked to investigate each system's limits and potentials. Case studies are carefully analyzed and graphically represented through a material lens. Beyond the analytical drawings, an understanding and application of the material systems is demonstrated through a translational design-build exercise, fabricating a full-scale pavilion. After having worked first-hand with the material systems at an intimate scale, students employ the material systems, with greater skill and complexity, in a larger project with a public program and urban site. Looking at the semester's work as a continuum, there is a clear thread of development with each exercise building upon the previous. The final project outcomes demonstrate the ends of a pedagogy at full-scale: leaving students with an applied understanding of how a material and its associated systems of assembly can be intertwined in a project-based design-process to generate the performance and experience of architecture.

To demonstrate the exercise's effect, a comparison of student work samples from previous years that did not include the full-scale exercise component will be presented.

PEDAGOGY: PROTOTYPING AS DESIGN RESEARCH

Within the academy, research and practice are typically pursued as separate endeavors, in distinct environments, and rarely are both pursuits undertaken by the same person. As the definition of these terms softens and their breadth widens, an opportunity presents itself to conjoin the two towards a singular goal. In recent years the term "research" has been appropriated from traditional text-based scholars by practitioners to validate their exploration-based design process: research through making. The subject and/or medium of much of this "design research" is material(s) and its associated tools, processes, systems, assemblies, or applications. Once marginalized amidst the digital revolution, material studies have acquired a newfound agency and platform within contemporary discourse. Although now pursued by practitioners, this research is still distinct from traditional practice. Practice still operates in a studio environment, in which project-based studies (i.e. buildings) are the norm; whereas similar to traditional research models, material research is contained within workshops and seminars. Sadly, even with a proliferation of course offerings on material research, the development of material systems continues to be a secondary concern in the studio. In my experience, students have a limited ability to negotiate the distinct processes of the two modes and to apply the intellectual capital acquired through a seminar's material research towards his or her studio's project-based assignments. I fear that without proper instruction, these two modes of inquiry will remain as parallel studies.

Leveraging Material's elevated platform within the discipline, I've folded the two modes into a singular process, integrating full-scale material research into a studio's project-based design-process. The pedagogy adopts a non-linear working-scale sequence that positions material prototyping exercises within the early stages of a studio project's conceptual development. These full-scale exercises prompt students to embrace, and design with, material specificity: linking tectonics and geometric forms with a material and its specific attributes. This coupling of materials and tectonics encourages a design process that integrates production techniques and strategies into the creative process towards the realization of the material tectonic and its resultant material effect. Prototyping provides an opportunity for students to test both the effective and affective qualities of their material assemblies and make necessary design adjustments. Two types of prototypes are utilized: a fragment and a whole. A fragment is a smaller-sized assembly, roughly the size of the body, in which connections, scale, and material qualities are evaluated. A whole is a full-sized assembly, which provides opportunity to have an experiential engagement, and to evaluate tolerances, durability, and assembly sequences.

CASE STUDY: COURSE

The case study course is an undergraduate studio taken during the fourth semester of a ten-semester curriculum, where materials are introduced as a topic and design primer.[1] Topics of the three previous semesters include spatial design, generative form making, and site. Entering the fourth semester, students have great technique in developing homogenized objects as a digital and physical model, and representing their likeness and (formal) developmental process through vector-line drawings. At this stage the work lacks element distinction, required of projects that are comprised of heterogeneous elements such as material, components, or assemblies. At first glance the work resembles Peter Eisenman's infamous house project series, although making the houses appear as dematerialized models was Eisenman's design intent. The case study course (the course) presents an alternative material-centric process; one that pushes material consideration to the forefront of the design process and utilizes a bottom-up (systemic) approach to form making. Conceived as a singular investigation with multiple developmental exercises, the course utilized a precedent analysis exercise and a design-build exercise (material research) as supplemental instruction towards the formulation of a material-centric project-based design process.

Throughout the semester, students were repeatedly challenged to re-think their material systems at different sizes, scales, and shapes in a non-linear sequence: oscillation of project size from building to pavilion to building, shifting working scale from 1:100 to 1:5 to 1:1 to 1:100, and morphing site boundary-shape from irregular to rectangular to triangular. In addition, the medium of investigation ranged from analytical drawings to material prototype to graphic representation to physical models to full-scale constructs. The only constant was the students' material systems.

CASE STUDY: PRECEDENT ANALYSIS

Precedent analysis and representation was the first segment of the tripartite course. The use of precedent is a well-established analytical tool for unpacking the concepts, systems, and principles organizing a design project. While its investigative potential is broad, our use of it was narrow: focused solely on the material system(s), material tectonic(s), and material implications of design. The developmental exercise provided an initial glance into how material systems shape the form of a project through its structure, and the perception of a project through its envelope. And importantly, how the two material systems – structure and envelope – can have a relationship that is mutually beneficial and codependent.

Assigned to each studio of twelve students were six precedents of specific historical significance. In an effort to promote systematic diversity, each of the six precedents represented one of following primary building materials: timber, steel, concrete, masonry, glass, or plastic. This material diversity at a systematic level established fundamental distinction between student projects, as students were prompted to retain their material systems throughout the semester. Through analysis, students (working in pairs) developed a detailed understanding of their precedent's material systems including: material qualities and limitations, unit sizing and spacing, methods of assembly and production, etc. Through representation, students developed techniques and conventions for graphically communicating their systems' material logics and qualities including: proportion, order, rhythm, texture, color, etc. The desired outcome of this exercise was a lucid understanding of each precedent's systemic formation, or generative instructions, that established the formal relationship between structure and envelope.[2]

CASE STUDY: DESIGN-BUILD EXERCISE

A design-build pavilion was the second segment of the tripartite course. Employed as a developmental workshop that was nested within a studio course, the small-sized yet full-scale exercise introduced students to material research through an integrated project-based design-process. Advocating depth over breadth, students were prompted to continue their study of a single set of material systems by adopting the structure and envelope systems from their previously studied precedents, and utilizing them in their pavilion design. Prior knowledge of their material systems provided an elevated platform to begin the design process, and students were able to quickly engage in advanced material investigations.

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Figure 1: Penta Pavilion, at full-scale.

The project had two components – design and build – that were split into two separate three-week investigations with different internal team organizations.[3] For the "design" component, the six student-pairings from the precedent exercise continued their working relationships to complete the pavilion design component. However, only one of the six pavilion designs was realized at full-scale as the “build” component (Figure 1), with the entire studio participating in the selection and fabrication of the chosen pavilion. The “build” component’s team organization was more complex and required faculty involvement as a project manager.

To begin the project and kick-start the shift from material system analysis to full-scale material making, students participated in a faculty led one-day material training workshop that was focused on cultivating material craftsmanship in a single material category: timber, steel, concrete, masonry, glass, or plastic. Each workshop included two parts: a demonstration and a task exercise. For example in the steel workshop, students were introduced to the school’s metal working tools and provided a demonstration of appropriate connection methods such as welding, pop riveting, screwing, and bolting. The introduction was followed by a task exercise that required them to work with the material in different profiles (sheets, tubes, etc.) to achieve a specific design performance. By the end of the short workshop, students had a basic understanding of how to work with their material and to utilize appropriate connection methods.

For the “design” component, the project’s limited scope was strategic in allowing for unmediated design development of the pavilion’s material systems. Standing on the shoulders of distinguished precedents, students were challenged to demonstrate an applied understanding of their precedent’s systemic formation or generative instructions through a systemic evolution of its two material systems. Systemic innovation required an understanding of each system’s specific design performance criteria, and recognition that the system’s performance criteria will transcend its materiality. To this point, each material could be employed as either structure or envelope; yet in order to meet the system’s design performance criteria, the material’s tectonic assembly would differ for each system. Due to the vast difference between the precedents and the pavilions – in size, performance, and scope – the material tectonics of the former could not be directly applied to the later. A thoughtful translation was required, mutating the generative instructions of the precedent’s material systems and developing new material tectonics.

There was a common misconception amongst students in regards to how much design thinking and documentation still remains in the build phase. And importantly, how the detailing of connections and material assemblies is critical in the realization of a design concept. The “build” component’s team organization was primarily horizontal with the exception of the pavilion’s original designers who circulated between sub-teams to provide knowledge and instruction on project’s design intent. As project manager, I identified three areas in the original proposal for additional design development, and assigned four students to each sub-team. Each sub-team developed a series of shop drawings, fabrication gigs, and 1:1 prototypes to test and advance the project’s design intent through material tectonics (Figure 2). With limited but specific responsibility in the project’s design development, students had their own piece of the project; this team structure developed pride in ownership and helped students become vested in a build project that was not their own pavilion design.

CASE STUDY: LIBRARY PROJECT

The library project was the third segment of the tripartite course. The first two introductory exercises provided a foundation of material knowledge that could be built upon with a material-centric project-based design process. After having analyzed their material systems at a building size, and worked first-hand with the material systems at an intimate pavilion size, students were better equipped to employ their material systems towards a material-centric library design. In this

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final segment, a larger project with a public program and a challenging urban site, students worked individually to advance the material systems from their precedent studies and pavilion design proposals.[4]

In adapting and advancing their material systems, this project included three additional design factors to consider and resolve: site shape, building size, and program demands. A complex triangular site bounded on each side by sidewalks and streets to establish an urban island condition with all sides exposed. A topographically rich site, it is triangular-shaped when viewed from above albeit with four elevation points; each perimeter side is slopped, irregularly but in a constant downward direction, to produce four elevation points: a two-story height differential at one lot corner (two elevation points) and transitional pivot conditions at the other two lot corners. A multi-story building proposal is required to accommodate the program's area on a relatively small lot size; students could call upon their precedents as a reference for member sizing and spanning capabilities. The library program included a diverse range of spatial performance criteria, public and private zones, and distinct rituals of inhabitation.

CASE STUDY: SYNTHESIS

This course is a successful example of using a synthetic material pedagogy that links precedent analysis, full-scale material research, and building design project together in a singular course structure. Full-scale exercises have agency and are employed here as a means to an end, to introduce material specificity and research into the studio design process. The students' building design projects

Figure 2: Penta Pavilion, prototype and material testing.

(final project outcomes) demonstrate the success of the pedagogy in cultivating deep investigations into material systems within an entry-level course. To illustrate the continuous thread of development in the semester are two examples Calvin Boyd (Figure 3) and Amelia Lin (Figures 4 and 5).

Calvin's precedent was the Agbar Tower by Atelier Jean Nouvel. The tower's elliptical shaped geometry is composed of a concrete wall exoskeleton, punctured by pixilated apertures, and glass louver curtain wall envelope. Although the two systems have unique performance criteria, their generative instructions are intertwined and codependent. The envelope's unit increment (frame and louver) is set by the glass louver's material limitations as a horizontal span; the increment wraps the tower's circumference planimetrically as a radial grid and in elevation as a surface map (parallels of latitude and meridians of longitude). Derived from the unit increment, the pixilated apertures of the concrete wall exoskeleton establish the floor-to-floor heights (vertical parallels) and the connection points of the envelope's frame into the structural wall (horizontal meridians). For his pavilion design proposal Calvin translated the envelope's singular orientation, wrapping the exterior of a cylindrical tube, to an oscillating condition where its orientation shifts from interior to exterior, similar to a Möbius strip. To achieve this effect the primitive evolved from a cylinder (elliptical shaped tower) to a cone; the primitive cone was duplicated and inverted so that along one ruled-edge the two primitives merge into a singular object. The envelope's surface grid varies due to the cones' geometry and its non-parallel lines of longitude, and the designer's rotation of the parallels of latitude to produce a spiral effect. The new surface map generates a pixel profile that is trapezoidal and variable. The glass louver increment remains constant but now oriented vertically along the cone's meridians of longitude. For his library design proposal Calvin continued his study of the mobius effect albeit through a singular (external) orientation. To achieve this effect the primitive evolved from a cone to a torus-like geometry with a rectangular profile shape. The sectional profile rotated around a central axis to make a three-quarter rotation per revolution around torus; lack of a full rotation produced the mobius effect, or rather an infinite loop. The envelope's unit increment is generated through a radial grid with the glass louver frame aligned with the section profiles and the standardized glass louvers oriented perpendicular to the surface normal.

Amelia's precedent was the M.I.T. Chapel by Eero Saarinen. The chapel's cylindrical geometry is composed of a brick masonry wall exoskeleton and an undulating brick masonry curtain wall envelope on the interior side of the cylinder. The two systems utilize the same material towards different ends – both performance criteria and aesthetic effects – while using intertwined generative instructions. The perimeter (cylindrical) structural wall distributes its load onto twelve irregularly spaced peers, symmetrical along a central axis, through irregular arches that span between each peer-node. The peers sit in a circular reflecting pool that extends below the building under the archways. The sinuous interior curtain wall aligns its variable frequency and crest points to the structure's peer-nodes; the geometry of the curtain wall is internally offset to form a third layer, a lower wood railing wall. The gap between the two internal walls produces a linear aperture, an inverted skylight, with indirect light emanating from the reflecting pool below. For her pavilion design proposal Amelia maintained a two-wall system, external structure and internal envelope, and utilized the cavity between them to filter light. Circular skylights between the walls utilize the sinuous internal wall's generative instructions for positioning and size. The relationship between the

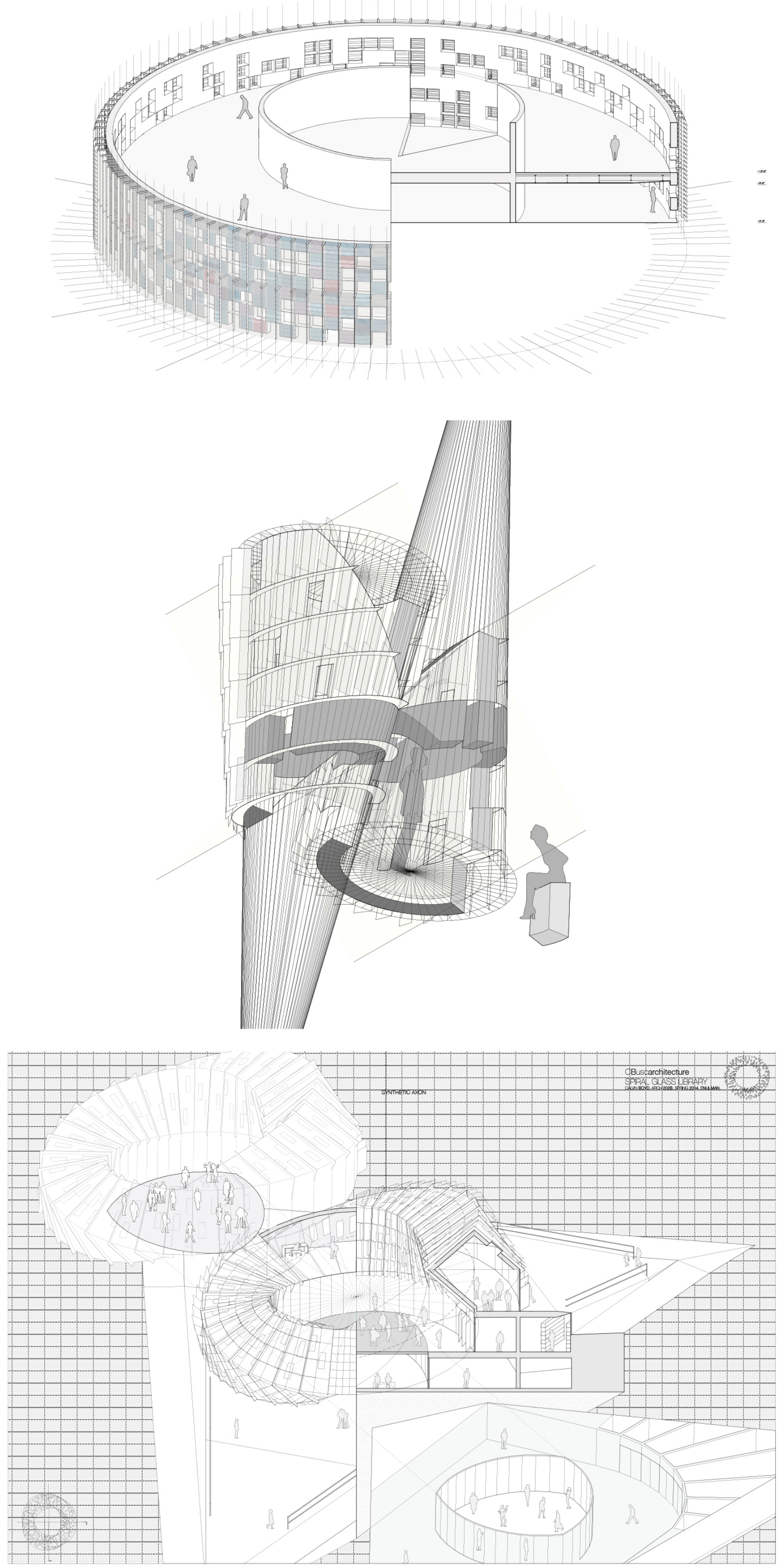

Figure 3: Calvin Boyd, Synthesis of projects 1, 2, 3.

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standard brick size and the radii of the undulating internal wall generates gaps in the brick coursing. These gaps allow light to filter through the wall and into the interior space while still concealing the light source. For her library design proposal Amelia continued her exploration into light filtration and porous masonry curtain wall systems. Her brick coursing advanced from an extruded wall to a three-dimensional wall undulating in both plan and section. A multi-storied cylinder with a cavernous wall-cavity topped with rhythmic skylights above, channel daylight deep into the library. The profile shape of the floor's perimeter follows the logic of the internal walls' geometric frequency and utilizes the crest points to connect to the outer structural wall at crest points that vary from floor to floor. The wall's curvature in both plan and section informs the gaps in the brick coursing to allow light filtration.

CROSS YEAR COMPARISON

To explicate the pedagogy's effect, a comparison of student work samples of the same course from previous years that did not include the full-scale exercise component or interwoven projects. Although the course topic and learning objectives were of a similar vein, the course's structure and exercises were different. The old course emphasized breadth over depth through a series of five

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disparate exercises that introduced unique aspects of a material centric design approach: [1] Material/Precedent, [2] Assemblies, [3] Performative Object, [4] Material Systems, [5] Material Architecture. In comparing the two courses, the first and last exercises are nearly identical but the exercises in between are distinct. "Assemblies" introduces the relationship of connections and larger systems

Figure 4: Amelia Lin, masonry pavilion proposal.

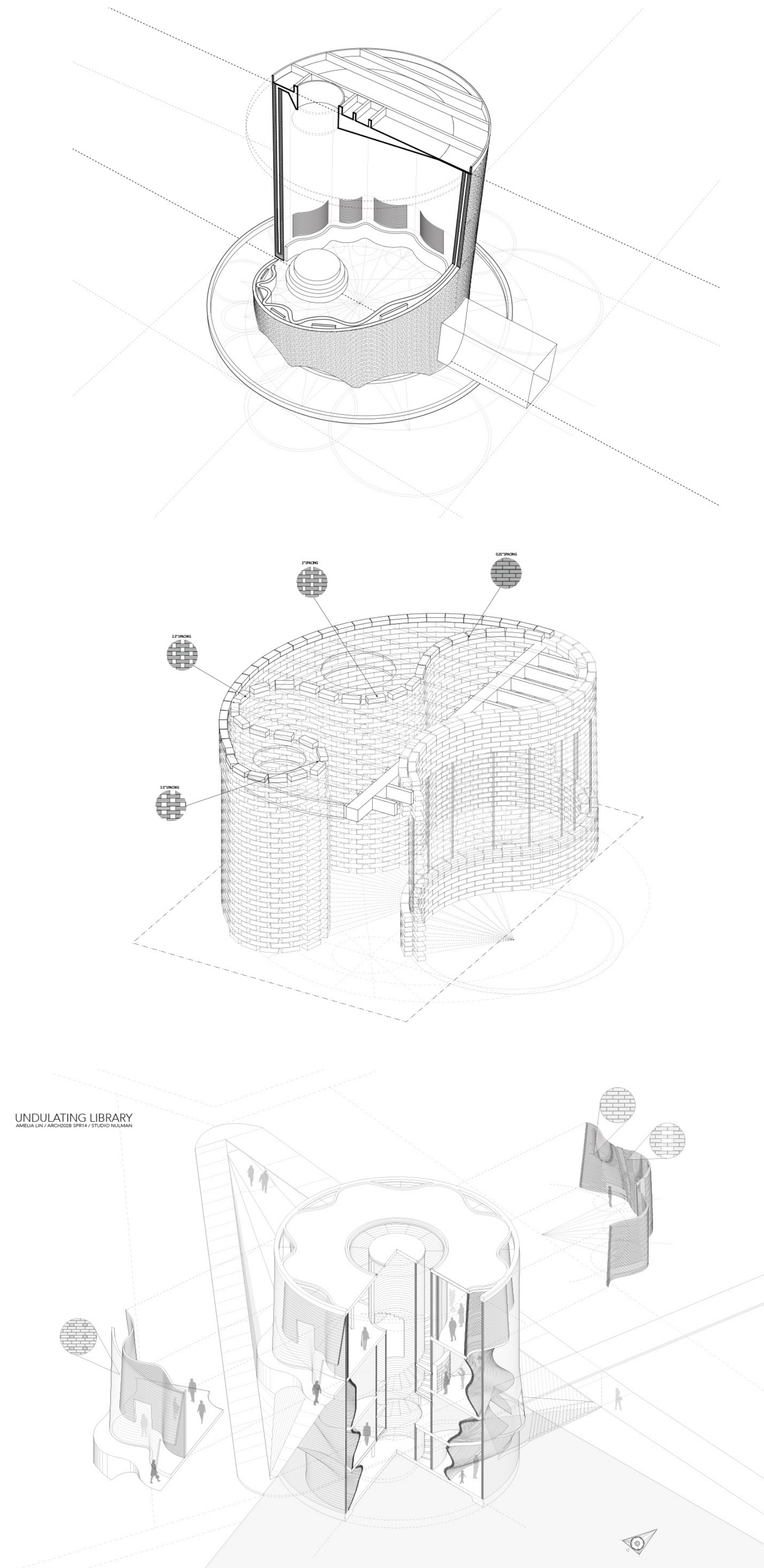

Figure 5: Amelia Lin, synthesis projects 1, 2, 3.

of assembly through the use of a specific material unit (wood 2x2x12) and a limited collection of operations (cutting, drilling, notching) to develop an individual tectonic. The final assembly is a desk-sized sculpture/model with many parts connected with only glue. "Performative Object" introduces function or program with the material choice open and the final assembly is a bench. "Material Systems" introduces the limitations and capabilities of working within an existing system of material (concrete masonry unit). The deliverable was the design of a programmatically limited warehouse building. The breadth of materials studied in these three exercises (each lasting less than three weeks) provided a shallow foundation to begin the "Material Architecture" exercise and resulted in final project outcomes with an absence of material specificity and/or an understanding of material performance. The new course merged the objectives of these three disparate exercises into a single full-scale exercise (pavilion) to emphasize depth over breadth in understanding performance capabilities of a material system. In comparing the final project outcomes, the later course projects demonstrate through graphic representation a greater understanding of material system logic and performance, both in isolation and conjoined with other systems (particularly structure and envelope), including unit sizing, spacing, connections, and spanning capabilities.

CONCLUSION

Material studies, as integrated workshop exercises, are valuable pedagogic tools to promote and cultivate material agency in the studio design process. To enable material studies and studio projects to become a synthetic process, the material studies need to be explicitly linked to the studio projects rather than as disparate studies. A non-linear working-scale sequence positions material prototyping exercises within the early stages of a studio project's conceptual development to prompt students to embrace, and design with, material specificity. This intervention, in the digital or computational design process, has a lasting effect on a studio-project's development, marrying formal expression with material performance and system potential.

Full-scale exercises have agency and are employed here as a means to an end, to introduce material specificity, production concerns, and research into the studio design process. Research through full-scale making challenges the traditional working scale at which the design process begins, and the timing in which production techniques and strategies are considered. Students learned how the detailing of connections and material assemblies is critical in the realization of a design concept. And importantly, to produce and develop a set of instruments including shop drawings, fabrication gigs, and 1:1 prototypes, for others to use towards the realization of a project's design intent. Full-scale instructional exercises have their critical limits – time, money, facility resources, project size and complexity – but these limits are relational and circumstantial. In this course, time was our critical factor: a three-week production phase that had a ripple effect limiting the other factors. Yet still in that reduced time we were able to work with conventional building materials such as steel and timber, and use sophisticated fabrication processes such as water-jet cutting, CNC milling, and welding.[5]

Pedagogy at full-scale leaves students with an applied understanding of how a material and its associated systems of assembly can be intertwined in the creative process to generate the performance and experience of architecture.

ENDNOTES

1. The course, Arch 202b, was at the University of Southern California School of Architecture in Spring 2014.
2. A two week investigation, the precedent exercise included four deliverables: [1] a series of drawings that analyze and represent the precedent's structure (primary material unit, assembly, and/or system) [2] a series of drawings that analyze and represent the precedent's envelope (primary material unit, assembly, and/or system) [3] a large axonometric drawing of the building that synthesizes both the material system (analytical) and material effect (representational), [4] an abstract effectual interpretation of the material tectonic/unit of the precedent (i.e. material prototype).
3. The "design" component included four deliverables: [1] a series of drawings that analyze and represent the pavilion's structure (primary material unit, assembly, and/or system), [2] a series of drawings that analyze and represent the pavilion's envelope (primary material unit, assembly, and/or system), [3] a large axonometric drawing of the pavilion that synthesizes both the material system (analytical) and material effect (representational), [4] a large model at 1:6 scale. The large working scale required each tectonic element to be articulated, and enabled the systems to be modeled with actual materials (wood, metal, concrete, etc.). The "build" component had only one deliverable, a full-scale pavilion (Figure 1). A small-sized construct with a maximum footprint of only 10'x15', the project's materials could easily be procured, transported, handled, and tooled into manageable (both physical and conceptual) tectonic assemblies. Minimal programmatic requirements included the provision of space for three adults within the freestanding structure, and for the pavilion to be structurally competent throughout its lifecycle, a brief one-week exhibition.
4. The library segment included five deliverables: [1] a drawing that analyzes and represents the library's structure (primary material unit, assembly, and/or system) [2] a drawing that analyzes and represents the library's envelope (primary material unit, assembly, and/or system) [3] a large axonometric drawing of the library that synthesizes both the material system (analytical) and material effect (representational), [4] a series of orthographic drawings at 1:100 scale, [5] a physical model at 1:100 scale.
5. In retrospect, I waver on whether the full-scale exercise's pedagogic impact would be stronger if each student (or pair) spent the three-week fabrication phase completing a fragment of his or her own pavilion proposal, rather than completing one collective studio pavilion as described here. A pavilion fragment would serve as a material prototype for his or her own library project and advance the student's understanding of their specific material systems. However, a completed pavilion provided an opportunity to have an experiential engagement, which is at architecture's fundamental core, as well as participating in collaborative work environment.

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