Intersections Between the Academy and Practice

Applied Research in Architecture Education That Advances Practice

PAPER PROCEEDINGS

2015 AIA/ACSA INTERSECTIONS SYMPOSIUM

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CONFERENCE CO-CHAIRS:

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The Relationship of Form and Performance in Façade Design

Architectura autem constat ex-ordinatione, quae graece taxis dicitur, et ex dispositione, hanc autem Graeci diathesin vocitant, et eurythmia et symmetria et decore et distributione quae graece oeconomia dicitur. —Vitruvius[1]

AARON BRAKKE
Universidad Piloto de Colombia
Whiteknee

RODRIGO VELASCO
Universidad Piloto de Colombia
Frontis 3d

ABSTRACT
This article provides insight into how a concern for geometry and proportion has continuously influenced the design of building over time. The focus of the work included herein illustrates how environmental performance may be used as the principle organizing principle in the development of brise soleil systems. The examples presented have relied upon computational tools to understand the relationship between how iterative design developments of the building skin may evolve to improve levels of internal comfort.

INTRODUCTION

The context of this paper is found in an environment that aims to better bridge the academy and practice. What the authors provide in the following pages is a reflection of how undergraduate students are being guided to better understand how an architect might interpret and design for particular geographic and climatic situations. This is accomplished through both traditional and digital techniques that first aim to provide the foundation necessary to first analyze the geometric considerations for the building facade. The scope of these studies is limited to brise soleil systems and an interest in simulating and visualizing environmental performance. Prior to this, a reflection of the evolved criterion for the use of proportion and geometry is made to frame the shift in the way that several architects approached facade design with examples of contemporary practice. The basic structure of this discussion relies upon a light reflection of *form* and *function* in order to structure the conversation which is further filtered through the preoccupation with both the environment and computation. Though generally treated autonomously and independently of aesthetics, much value can be gained by considering synergetic possibilities. This paper will reveal what was learned from students that were required to conduct environmental simulations with the intention that they could better position themselves to become sensitive to urgent issues. Surveys have been conducted with the participants and the results have shown that students have embraced the prescribed methodology. A number of students have become interested in the classes to the extent that they have joined a small research group in which they are tutored and encouraged to engage in an exploration of digital tools to visualize, simulate, generate and fabricate. After several years of this work, one of the authors decided to pursue these interest in the private sector in a start-up. Several figures, both students and professors, have joined Velasco and formally established the company Frontis 3d which is a façade design, consultation and fabrication firm. It is used as a case study to illustrate the relation between the academy and practice in a way that veers from the design studio structure commonly utilized by architecture professors. The entrepreneurial spirit of this team has been bolstered by winning the Innpulsa competition which is providing matching funds for a variety of investments being made to better equip them.

MUSING: THE REPEATED RELEVANCE OF FORM AND FUNCTION

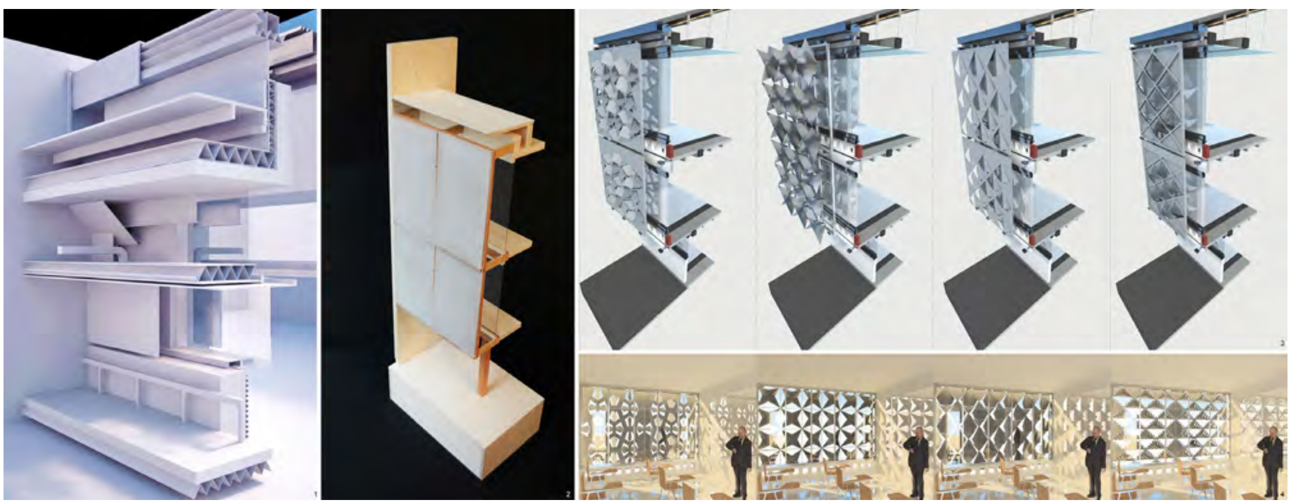
Referencing the writings of Vitruvius and his concerns two thousand years ago through the auspices of *firmitas, utilitas* and *venustas* has been and continues to serve as vital vocabulary for the framing and discussion of architecture. Alberti echoed this by using similar terms such as: commode, firmitatem and gratiam in his treatise developed during the Renaissance. The interest in developing formal harmony that responds to functional variables is seen in expressions, such as, "*Each part should be appropriate and suit its purpose. For every aspect of building….is born out of necessity, nourished by convenience, dignified by use, and only in the end is pleasure provided for.*"[2] The term function and its role in determining form becomes much more explicitly treated in more recent times. Viollet-le-Duc stated, "*There is in every building, I may say, one principal organ – one dominant part – and certain secondary orders or members…… Each of these orders has its own function; but it ought to be connected with the whole body in proportion to its requirements.*"[3] Louis Sullivan eloquently and succinctly articulated these beliefs when he created the maxim, *Form follows Function* in the nineteenth century. Though Sullivan's philosophy was rather profound and encompassed the social and cultural roles of building, his aphorism has served as the catch phrase slogan for Modernist architects that chose to taper the scope to an interpretation that only considered the expression as a sort of pragmatic tectonic muse. More than a century later, the role of function as the determinant of the built work continues to be a much debated topic. In this paper we choose to channel this discussion through a description of exercises that question the form of the façade.

CONSIDERING TENDENCIES IN THE RHYTHM OF THE BUILDING FAÇADE

The analysis and critique of the building façade has consistently maintained noteworthy presence within architectural criticism over time. An architectural student is always taken back to the Greek Orders when introduced to the fundamentals of architecture as described by Vitruvius. The eurythmia (rhythmic geometry) of the Santa Maria Novella façade that dressed an existing Gothic structure has been and will continue to serve as Alberti's key achievement in that it serves to express the principles articulated in his classic architectural treatise "De Re Aedificatoria". The principles of proportion have continued to be present in the architectural discourse as evidenced in the way Le Corbusier bridged 2000 years of anthropometric study by reflecting on DaVinci's Vitruvian Man and the golden ratio.[4] He, of course, emitted his own contribution through his study of the French man which was synthesized in the Modular which was further westernized and refined in Modular 2.

These proportions were manifested architectonically by Le Corbusier in projects such as Unite d'Habitation, the Church of Sainte Marie and in the Carpenter Center where they served as an organizing principle for the geometric dimensions in both plan and elevation. With regard to the expression of a building in its exterior, the Greeks established an interface between nature and human society through the Doric, Ionic and Corinthian Orders. Whereas for Le Corbusier, the articulation of the brise-soleil facade systems was restrained to the Modular proportions. However significant these projects and practices may be, they are only mentioned to introduce the notion that geometric rhythms have been and continue to be well thought out and contrived architectural maneuvers in the structuring, ordering and aesthetics of the facade.

A continued interest in geometric rigor continues to be present in architectural practice and in contemporary façade development. However, the contemporary post-digital modulation of the façade rarely echoes the form of the human body so literally. Observing a plethora of strategies being deployed in practice leads us to believe that there is no dictum nor even a set of guides (let alone standards) for the contemporary discourse. Often modulation loosely reflects current local code related standards, such as floor to floor heights or the limitations imposed by manufacturing, transport and on-site installation. Another possible route, the one the authors have chosen to reconnoiter, is to implore the geometries that correspond to the solar path. In regards to the human body, a shift has occurred from an interest in the representation of its proportion and form towards a performative concern for it: Aiming to create improved levels of comfort while minimizing the reliance upon active systems of heating and cooling. While simply stated, it is this aim that has been a guiding light for those interested in responding the environmental crisis. This article will demonstrate how the authors are exploring the way to which form can be informed in façade design through basic energy modeling and solar radiation studies. This article seeks to bridge academia and practice by providing a narrative that illustrates the work being done with students, in research and in practice with the intention of providing a modest example of work from South America.



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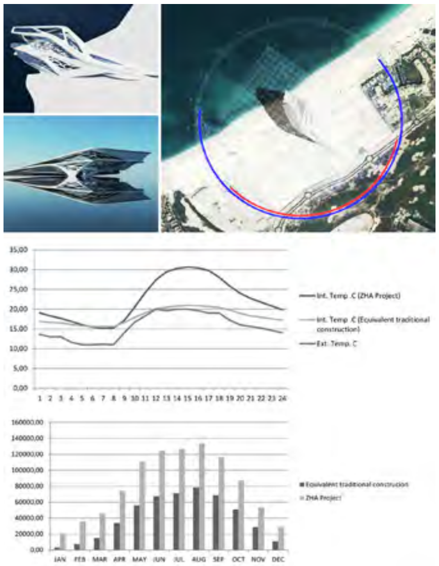
CONSIDERING PERFORMANCE

An interest in the relationship of computation and design process has become very evident over the past half century. In recent years issues such as; BIM, Shape Grammar, Parametric design, Digital fabrication, Robotics, Cybernetics, Virtual Reality, Surface, Scripting, Morphogenesis, etc. have been widely discussed. The scope of this article is limited to a discussion of a Performance based approach to design. This tendency considers how function determines form by contemplating the role of performance. In a 1984 edition of Yale's Perspecta, in an article titled "Critical Architecture: Between Culture and Form", K. Michael Hays argues against the dichotomy of either understanding architecture as being an instrument of culture or as architecture being an autonomous form in favour of the in-between that cuts across this opposition. The performance based approach to architecture is an in-between stance that neither limits the reading of architecture to

Figure 1: *Tecnologia V Facade Modulation Studies:* Spring 2014 & *Graduate Project - Axonometric Drawings and Interior Perspectives* Fantolvo, Gonzalez, Leon & Tocancipa



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cultural production nor to the formal operations of creating the autonomous architectural object.[5] While both tendencies utilize iterative processes, the performance based approach addresses the complexity of the contemporary conditions more holistically which is fundamentally dynamic and non-discrete.[6] Performance based architecture relies upon an iterative process that may incorporate simulation, analysis, optimization, visualization and fabrication in the generation of form.[7]

INTRODUCING STUDENTS TO THESE TOPICS AND EXPLORING WITH THEM

The issues contemplated in the previous section have been addressed in a variety of contexts by the authors. Participation in multidisciplinary university research projects that have utilized a parametric design process, building information modelling, simulation and evaluation and physical prototypes has been the first scenario. The results of this research then filtered into the undergraduate curriculum in required electives and thesis projects which has led to offering certificate courses open to practitioners. Furthermore, one of the authors has garnered a group of like-minded practitioners to pursue this in a start-up company that provides façade design services.

The methodology utilized in this research, both in the academy and in practice, has involved a literature review, the analysis of existing projects and the generation of design proposals. A focus of this work has involved the modelling, simulation of solar radiation, ventilation and daylighting with Ecotect and Design Builder. The aim has been to gather a sample from various regions of the world in which the comparison and evaluation of the performance of traditional buildings with the behavior of contemporary interventions informs design generation.

The analysis of buildings has proven to show stark results between design intent and design performance. As professors of architecture, it is necessary to explore and understand the fundamental differences of critical theory and instill a desire in the minds of our students enquiry that also encourages them analyze both the written and built work of practicing architects. As student research tends to be rather superficial, motivating students to develop critical thinking about the aforementioned issues is a challenge. Being that media sources privilege the graphic image, students often develop intrigue with the building presented solely based on aesthetic considerations. While aesthetics is an important aspect, a limited reading of architecture to this area neglects a multitude of other factors that influence the built environment and the experience therein.

Students chose projects that interested them, but were asked to choose contemporary projects in which they could illustrate the use of digital tools in the design and/or fabrication process. An expanded comparison of projects by Zaha Hadid Architects (Fig. 2) and of Norman Foster and Partners is being conducted to be used as a way to contrast Parametricism with Performance based design. This analysis relies heavily upon digital simulations to gain insight into building performance. Working within the classroom environment also leads to interesting discoveries in design learning. The observation of student behavior as well as written surveys have been used to gather information about the perception of the design process, how digital tools are used, and how an architect should address environmental design.

RESPONSE FROM THE STUDENTS

This research is not exhaustive nor conclusive, however the preliminary findings have revealed several discrepancies in the theory and practice being developed. These discrepancies cause the authors to reflect on the validity of such theories and encourage more work in the area of performance.

Figure 2: *Geometric and Energy Modelling of Abu Dhabi Performing Arts Centre - Zaha Hadid Architects* L. Gallego, C. Diaz, A. Brakke & R. Velasco

As for the influence this project has had on the student participants, greater levels of confidence in rationalizing design problems has been witnessed. This has subsequently led to better clarity of the design problem and therefore higher levels of articulation in their projects. Excerpts from the surveys include comments, such as:[8]

> *"Permite mayor comprensión y precisión, sirve para organizar las ideas… se puede probar todos las ideas que tengan. …. Se afecta el diseño volviendo las ideas más reales." —Pedro Villate*

> *"…..desarrollo integral - generar simulaciones - visualizar - agiliza los procesos de fabricación - así que revolucionan totalmente el proyecto desde la planificación hasta su generación." —Anatoly Murcia*

> *"Es mas fácil y eficiente la representación de ideas y de demonstrar los conceptos implementados. Además permite la implementación de nuevos elementos más complejos y hace posible su realización." —Jaime Alfonso Olaya*

It is the hope of the authors to provide material that serves as a study to substantiate the discussion of pedagogy in the architectural debate. Working with students and gathering feedback from the process has served to better understand how contemporary topics are being confronted by the future generation. Though architectural design may be addressed from a multitude of angles, we have found that computation and environmental issues continue to be marked by the students as important concerns. Studies such as this offer insight into how this intriguing contemporary discussion and the evolved relationship between form and function.

3

FRONTIS 3D: LINKING ACADEMIA TO PROFESSIONAL PRACTICE

Frontis3D is a commercial company that designs, develops and produces special façade systems that minimize the energy consumption of buildings. The process incorporates design tools that allow manipulation of shapes and parameters of lighting and air conditioning (temperature control, humidity and air renewal), providing high performance in terms of environmental aspects.

The company's history is tightly linked to academia. It started with a research interest which was focused on building envelopes. This was the theme its main founder had been exploring back from his undergraduate years, which became a thesis project and a PhD research study developed in the UK. Velasco returned to Colombia with this specialized knowledge and continued to work on this research agenda. Over time, façade systems were the subject of taught modules and research projects at several universities in Bogotá, where a network of interested students and colleagues was developed. The commercial project took almost 7

Figure 3: *Between Frontis 3d Brise Soleil System and Existing Structure* (Photo:A. Brakke)

years to materialize, and included a number of former students and two students involved in the young research group as partners in the company at its founding. Right now, with three years in the market and some 15 projects built, the company has an important R+D basis that needs to keep developing, and for that reason, various ventures in partnership with academic actors are still being sought.

Besides providing high environmental performance, Frontis3D's custom made façade systems are also potential instruments of promotion and corporate identity thanks to the flexibility in the design process, the incorporation of elements of innovation from the customer's point of view which is achieved by using codesign as the main approach. An example of the company's work is the volumetric façade system developed for SEM Ingenieria, its manufacturing partner (Fig.3-6). For this project, long talks with the owners took place at the beginning of the design process, which subsequently became a list of parameters to include in a design definition that was then informed by simulation and optimization results based on daylight levels.[9]

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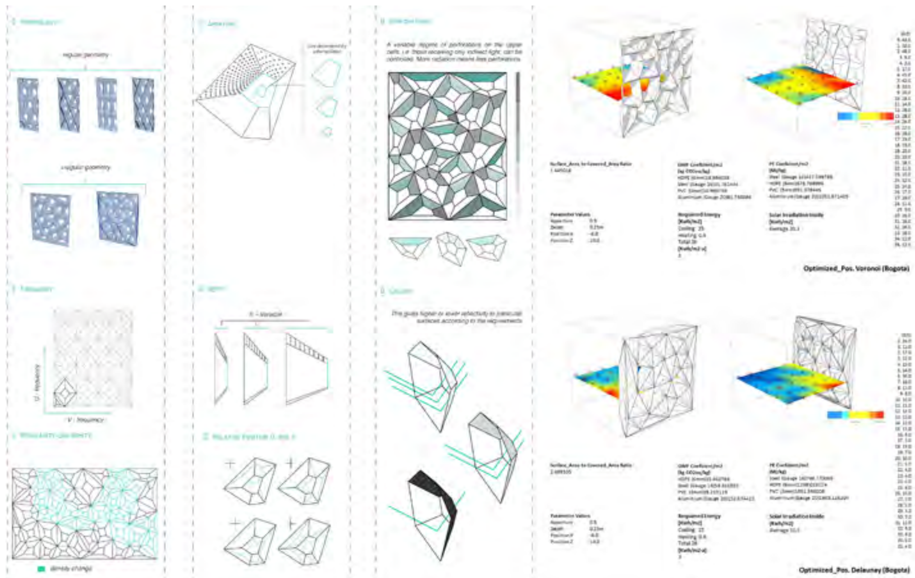

The result was an attractive looking brise-soleil system that satisfied both the client's image requirements as well as the specific environmental conditions of the site. The development of this article involved interviews with several members of the Frontis 3d company as well as a post occupancy survey of SEM employees and a lighting analysis of the facade intervention.

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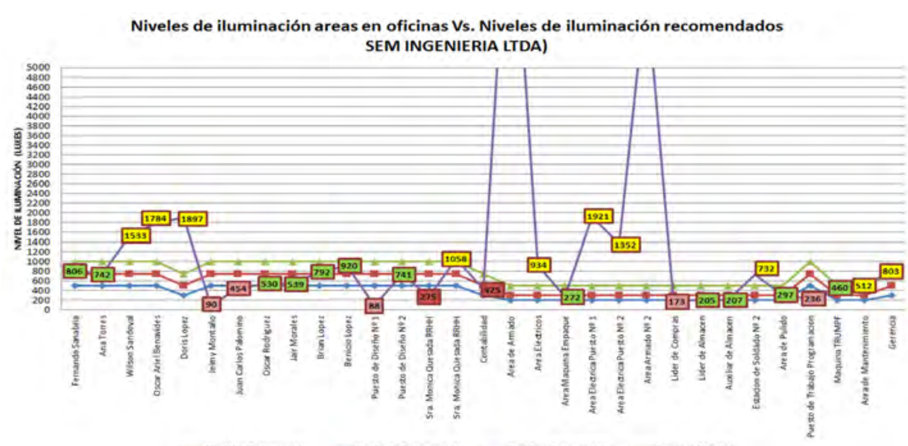

Figure 4: *Diagrams that illustrate design variables and simulations* (Frontis 3d - R. Velasco)

Figure 5: *Lighting Levels in SEM Facilities* (Geosecuritas)

6

The report shows that the employees have a positive perception of the intervention. What it reveals is that the lighting levels are superior to the recommended levels (Fig. 4 &5), however, this was the expected outcome which was communicated at the design stage. The clients made the decision to compromise optimal interior day lighting in favor of enlarged apertures that permit increased viewing toward the exterior streetscape. Maximizing affect while lowering material usage also played a part in the development of the voronoid modules. Ultimately the clients also did analyze the various geometric configurations in terms of aesthetic fitness.

CONCLUSIONS

Based on the literature review and case study analysis carried out in terms of research and developments in practice, we can attest to an evolved understanding of geometry and proportion. The design methodologies for façade systems that aim for high performance environmental solutions are far from mature, yet steadily improving. There are two main reasons for such growth: On the one hand, the need for better performing environmental systems to help cope with the current environmental crisis continues to have traction within the discipline and with society at large. The second reason is that the relatively recent advent and popularization of computational tools allows for a profound level of simulation that was previously unattainable without highly specialized engineers. In this context, the work shared in academia and practice may serve as a modest example to help build upon other research being conducted to promote the understanding of how brise-soleil systems improve the environmental performance of buildings. The bridging of the academia and practice through the case study of Frontis 3d also shows an entrepreneurial model that may serve as an example for others that opt for something other than the typical model of the design studio firm.

Figure 6: *Frontis 3d Brise Soleil System* (Photo:A. Brakke)

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Academic | Practice Partnership—Developing Responsive Architecture

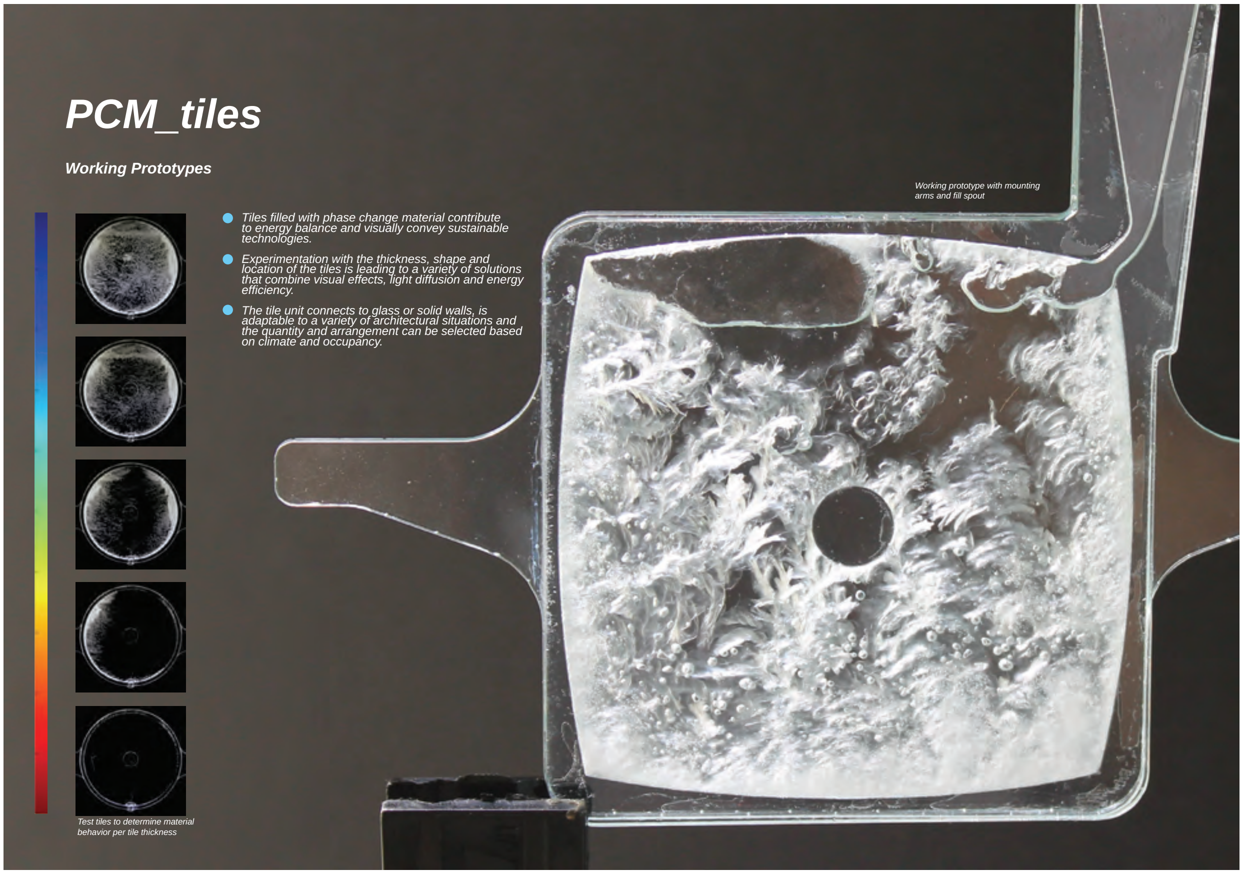
The Bio_Logic Design Group develops adaptive building technologies derived from emerging materials and biological principles. The group was formed to develop responsive architectural systems that bridge art, architecture, technology and engineering, and is housed in the College of Architecture and Environmental Design at Cal Poly.

DALE CLIFFORD
California Polytechnic State University

ABSTRACT
Academic entities have the ability to assemble resources and form 'local labs' able to creatively address complex technical problems. This paper describes academic partnerships with professional practice that offer responsive materials design expertise not available in many architectural firms. The following projects are funded by grants, gifts, and consultation mechanisms with architectural firms during the Request for Qualifications (RFQ) and the Request for Proposals (RFP) phase in competitive design solicitations. The RFQ and the RFP mechanisms are high-value low-risk means for architectural firms to add research and development capabilities to their project team. Example are given of two collaborative projects that have brought practice-based research to the architectural office and brought practical experience to students.

DESIGN PARTNERSHIP
Successful collaboration between academia and practice requires that each partner add value to the other. The medical and engineering fields have long depended on universities to advance basic research that is risky, expensive and lengthily, and when outcomes are not immediately applicable to commercialization. The fields of architecture and design are relative newcomers to academic | practice partnerships, though schools of architecture have historically relied on the transfer of knowledge from practitioners to students. Advancements in material development, manufacturing technology and digital media have altered the way architecture is conceived and constructed, and the pace of this change has accelerated academic | private partnership. Many architectural firms by necessity become specialized to focus human and monetary resources. Academia, in contrast, takes a more generalized stance, as the university derives its identity form diversity. These differences can form the basis of productive partnerships.

Productive academic | practice collaboration is built upon trust and the shared interest to support a climate of innovation. It is becoming more common for universities and professional practice to form alliances that advance both the state of design research



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and the ability of practice to more effectively handle complex design problems. Design research, as used in this paper, is defined as the advancement of design methods to produce a preferred state. Complex design problems are defined as problems that are outside the expertise of design firms and their general consultants. Responsive material research and application, technology that is being transferred from the medical, automotive and aeronautical industries, fit this category. Responsive materials change their physical properties in response to external stimuli and have the potential to make the built environment more responsive to climatic fluctuation.   Responsive materials exhibit a property change in response to a stimulus and are reversible. The benefits of a more responsive architecture are reduced energy consumption and the psychological effects of human awareness of environmental variation. The following projects describe an effort to make architecture more responsive to environmental fluctuation and to communicate this response to building occupants.

PROJECT EXAMPLE 1: FRICK PARK ENVIRONMENTAL CENTER

The Bio_Logic Design Group partnered with Bohlin Cywinski Jackson Architects (BCJ) in the RFQ and RFP stages of an international competitive project for the new Frick Park Environmental Center, Pittsburgh, PA. The project was directed by BCJ with the Bio_Logic Design Group contributing expertise in responsive building materials and as a creative engine to develop the visualization and interactive potential of sustainable technologies. An initial qualifications statement was prepared which included team members' affiliations and expertise. The team was successful and short-listed for the RFP phase. A number of pre-project and conceptual design meetings were help prior to the RFP presentation to client to outline the collaborative process.

Figure 1: PCM filled glass tile designed for the visualization of sustainable technology (Frick Environmental Center).

Site: Frick Park, Pittsburgh, PA: Frick Park is 644 acre park that has a sordid industrial history as it was a dumping ground for waste from Pittsburgh's steel mills. From 1920 – 1972 the topography within the park was transformed; it was constructed from repeated dumping of slag, a by-product of iron ore smelting. The main slag pile covers 238 acres and reaches more than 20 stories high, contributing to sever biotic impoverishment[1] of the area. Significant remediation is underway. This is the context for the new Frick Park Environmental Center. The mission of the Frick Environmental Center is educational and will bring diverse population groups in closer contact with nature through hands-on environmental activities. The Center will serve as a living laboratory for environmental design and educational practice as the building itself is intended to demonstrate sustainable principles to building occupants.

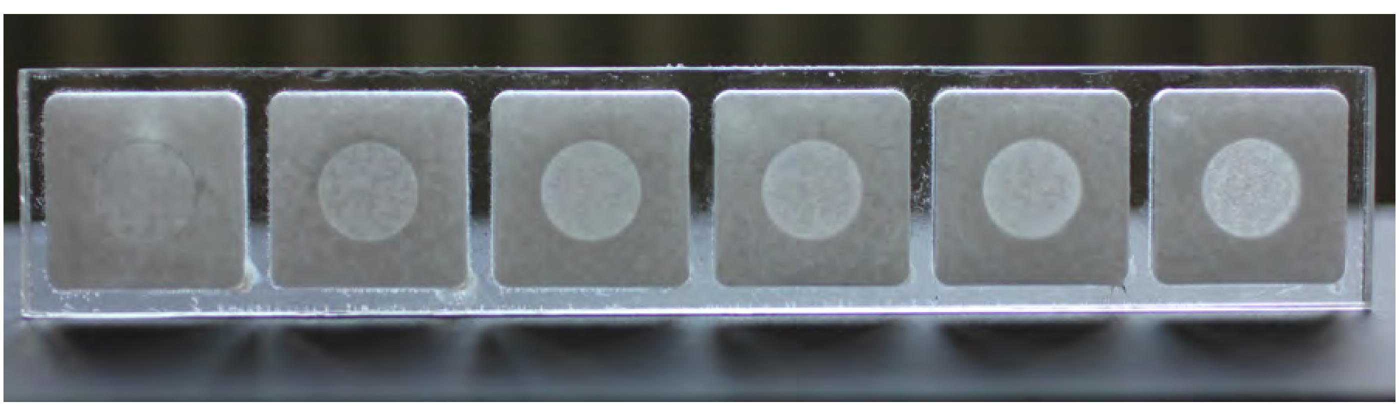
PROJECT BACKGROUND

The Frick project summarizes a collaborative effort between architect, consulting engineering firm and academic researchers to meet the energy petal of the Living Building Challenge for the Frick Park Environmental Center in Pittsburgh, PA. The team performed physical experiments and digital simulations to determine the ability of an emerging class of organic change materials (PCMs) to contribute to temperature balance and lower reliance on mechanical conditioning in a heating dominated climate, while contributing to the Center's educational mission to convey sustainable principles to the public. The work is also contributing to meeting LEED Platinum certification standards.

In response to the education requirements of Living Building Challenge, the design team (Bio_Logic Design Group, BCJ Architects, and TriPyramid) has designed a demonstration project in the main public gallery to showcase phase change material thermal storage devices. The teams' intent is to address the necessity to lower energy consumption by increasing the energy storage capabilities of the building envelope. Our approach is to use low-tech solid-state phase change material tiles for this purpose. PCM is also integrated into the building wall cavity, and helps to modulate internal temperature swings, lower reliance on building mechanical conditioning and met the energy petal of the LBC. The visual and tactile display in the gallery demonstrates the thermal storage capacity of PCM (Figures 1-3) and showcases the visual aspects of sustainable technology to visitors.

After the project was awarded through the RFP process, a contract was drawn between architect and consulting entity (Bio_Logic Design Group). Monies were then channeled from the consulting entity to the university in the form of a gift. The gift mechanism is similar to a grant, except that under the legal guidelines of a gift, the university extracts far less overhead, enabling a higher portion of monies to go directly to the academic project team. This method is currently under scrutiny, as university overhead, though it varies between

Figure 2: Experiment to quantify light transmission and thermal storage capacity.



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schools, is generally more than 50% via the grant funding mechanism. There is also a significant difference in terms of money allocation and deliverables. The gift mechanism is a riskier prospect as the giver of the gift has far less control over the use of the monies donated. There is no formal contract within the gift mechanism and no deliverables are specified.

PROJECT EXAMPLE 2: SOLAR PETALS

Solar Petals is a project initiated by architectural firm Arquitectonica through a grant funding mechanism to the university. The grant mechanism allowed the architecture firm to have greater contractual control over the project time line and deliverables. The partnership was initiated to add practice-based research to the architectural office and bring practical experience to students. This exploratory project sought to advance the architectural application shape-memory materials. The responsive petal array translates changes in sunlight levels to the interactive façade and communicates environmental fluctuation to building occupants. Solar Petals is a demonstration project is a step toward making architecture more adaptive to environmental change and to communicate this relationship to the public (Figure 4.)

PROJECT BACKGROUND

Designed for a new retail and housing tower complex in Miami, FL, Solar Petals is an interactive system that is responsive to sunlight and serves as an indicator of solar insolation available for powering the building complex. The technology bridges photovoltaic energy harvesting, sensing technologies, programming and shape memory alloy actuation. Project complexity required expertise from a collaborative team of students from architecture, electrical engineering, interaction design, the arts and computer science. The design/build process was the common language amongst the architectural office and the diverse student group. The team worked at 1:1 scale throughout the project and feedback from the prototypes catalyzed idea development and team-based decision-making. In this process, the act of making served as both a metric of proof and a method of creative inquiry. The scale of the models remained consistent, but the materials, actuating systems and phenomenal qualities increased in specificity and resolution. Full-scale working prototypes were used to communicate design possibilities and served as medium for the architecture firm to be directly involved in the design process.

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Figure 3: Interactive installation of PCM tiles (Frick Environmental Center).

Designed as an array of 900 petals, the array demonstrates the experiential potential of the relationship of environmental fluctuation and physical computation. Actuated by shape memory alloys, the petal array serves as an interactive facade that visually communicates the availability of incoming solar radiation to power the building to occupants.

HOW DOES PRACTICE BENEFIT FROM ACADEMIC PARTNERSHIP?

Practice benefits from university partnerships by gaining access to expertise and technology that is not currently housed within the office. Often this includes tapping into faculty and student ability, multidisciplinary contacts, and prototyping facilities. Academic coursework is somewhat resistant to economic pressures, allowing faculty and student teams to run through variations of an idea without direct monetary pressure. Academic teams are able to engage less constrained "wicked problems"[2] where the variables are fluid. The academic environment is also highly reflective and advocates critical evaluation to advance a design prospect. In partnership with practice, academia can effectively train students for emerging positions within practice that did not exist a decade ago. These positions require technical acuity, creative synthesis, and systems thinking skills.

In the cases of collaboration with Bohlin Cywinski Jackson Architects and Arquitectonica, collaboration generated knowledge exchange that included experience with responsive materials and designing innovative ways to visually demonstrate the qualitative aspects of sustainable technologies to building occupants.

HOW DOES THE UNIVERSITY BENEFIT?

Faculty and students benefit from external funding streams, the ability to work on advanced projects, and by gaining knowledge and feedback from practitioners. Practitioners provide insight into current issues of practice and enable curricula to respond to the variable landscape of practice with more acuity. Knowledge exchange from practice is critical to academia as the definition of an architect is continually being redefined. Past curricula focused on a set of relatively finite skills that would be useful throughout an architects career. More recently, there is an emergent curricula shift to focus on skills and

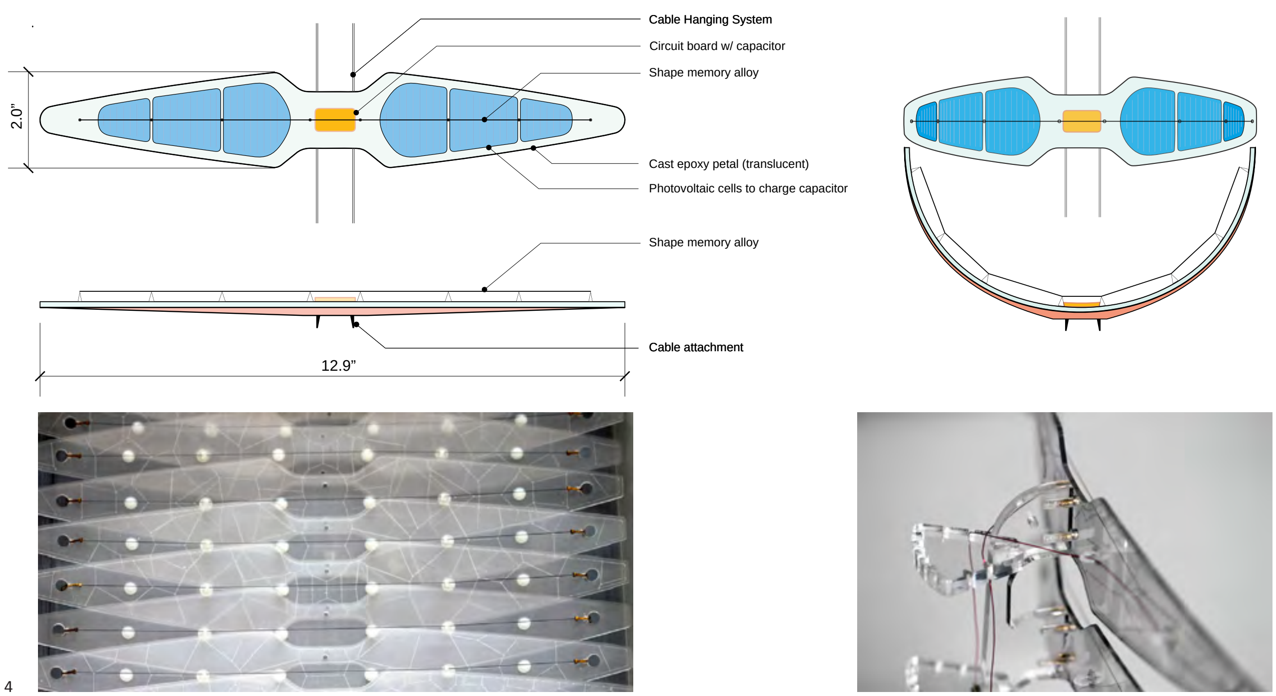

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Figure 4: Drawings of solar petal showing onboard photovoltaics that charge a capacitor to trigger the shape memory alloy(upper row) The first image illustrates the petal in the relaxed state, the second image illustrates the petal under charge. Prototype of solar petal array (lower row)

competencies while recognizing the pace of change in practice, and curricula is responding by shifting toward models that teach students to apply knowledge in novel situations. Educators train architects for an unpredictable future in terms of the boundaries of the definition of 'architect.' This redefinition becomes clear to instructors when student teams interact with design professionals to generate new knowledge through design.

PATHS FORWARD

KieranTImberlake, SOM and Perkins + Will are examples of small and large firms that make research explicit in their philosophical and pragmatic approach to design. These firms are among an emergent stream of firms that house internal research and development organizations that expand the range and depth of projects the firms are able to obtain. These firms are advocating a more porous boundary between design research and practice. As the spectrum of building technology broadens and the complexity of the design process increases, academic entities are poised to collaborate with private entities to train students for research and development positions that will add value to practice.

BACKGROUND NOTES

Phase change materials (PCMs) applicable to building technology include salts, paraffin and organic fatty acids. They have the potential to offset heating and cooling loads by serving as high mass thermal energy storage. Compared to concrete PCMs are far more effective at thermal storage during phase transition. Thermal mass has long been used to stabilize temperature in buildings and developed into a standardized technology by Edward Morse who patented the 'Trombe' wall system in 1881.[3] PCMs are a more recent advancement of this system, dating to the 1970s, and are effective due to the high heat of fusion generated when a material changes states. Today, PCMs are most commonly encapsulated in plaster then applied as an interior surface or encapsulated in plastic sheeting then applied behind drywall.

Shape memory alloys exhibit shape change characteristics in response to temperature change. The alloys used in this project are a composite of nickel and titanium and contract 5% of their length and serves as a non-mechanical actuator for the petals.

ENDNOTES

1. *Barrow, C. J. (1990), The Earth in Transition: Patterns and processes of biotic impoverishment edited by G. M. Woodwell. Cambridge University Press, Cambridge and New York, 1990.*

2. Rittel, H.W.J., Webber, M. M. (1973), Dilemmas in a General Theory of Planning. Policy Sciences 4, 2 155-66.

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Practicing Design-Build

This relationship (computation) is disconnecting our profession from the feeling of swinging a hammer or driving a screw. Yet we face a true challenge where the computer is not only necessary in the digital age we find ourselves living but used correctly it is a true asset. We must begin to train our students and professionals how to design in digital space without losing sight of gravity, structure, assembly processes or materiality. The studio explored a series of relationships; research to practice, academia to the profession, design to materiality + prototyping and digital to physical environments. The exploration of these relationships destroyed the students understanding of what each relationship was and rebuilt their perception of each relationship.

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ABSTRACT
The disconnect from academia to practice from design to construction is carrying the Architecture profession out to sea. Students and young professionals are further disconnected from the reality behind the representation of each line. This paper discusses a studio structured to mimic the professional environment while at the same researching through prototyping pre-fabrication, modular building, DfD (Design for Disassembly), and panelization theory including on-site/off-site construction methods. This body of applied research proves student's abilities to design are dramatically increased through hands-on experience. They suddenly understand the implications of each connection, detail and callout on their drawings. The studio operates under the auspice of two divisions within a single firm, collaborating and working independently when appropriate. The studio mimics firms by "hiring" Project Managers, Construction Supervisors, Digi-Fab Specialists, Design Presentation, Materiality and Donation Teams/Groups. This paper demonstrates the process for collaboration and cross-pollination for two simultaneous design-build projects. This paper will prove that through building in multiple mediums students not only blur the disconnect from academia to practice but also from design to fabrication and construction. One of those methods is simulative modeling, which cannot be comprised of lines that represent parts; it however must be crafted by elements and assemblies of parts. Simulation modeling creates the opportunity for architects to develop a case-by-case kit of parts.

The studio examined conditions of architecture and the potential of how design and construction synergies will influence building typologies in the next century. Building

upon the skills and knowledge developed from the master builder, the studio investigates architectural conditions by incorporating traditional making, digital fabrication and the computer as design tools. If we as architects intend to use technology to become true 21st century "master builders" we must understand that the term entails a very different set of parameters than it did 500 years ago. The investigation becomes a fluid integration into constructed principles. To achieve these goals and give students the experience of trade a series of workshops are taught including specific instruction for software and hardware which proved instrumental in materiality, connection and other important design decisions.

Suddenly when the responsibility of the product literally fell in the hands of the students their awareness and design decision making was heightened, improved and pushed in order negotiate cost, design and feasibility of fabrication and construction. This research has proven the void from education to practice is experience, or hands on experience. We are losing our profession to a digital age of slowly eliminating the relationship of the Architect to building. This is apparent through the introduction of BIM, where instead of drawing lines, information is entered through (some) spreadsheet data. This design-build studio serves as a driver for theoretical, experimental and abstract conditions that not only manipulate the way buildings are made but allows a master builder of the digital era to emerge in the 21st century. Without a drastic change in the way architecture addresses the experience and understanding of how we build we will ultimately drive our own obsolescence as a profession and as a society.

A single disconnect from Academia to practice would suggest an easy solution to our detachment could be found by simply putting our heads together. Rather than a single intersection, many disconnects between Academia, practice and the disciplines of architecture, construction, fabrication and design exist and these severed relationships are destroying the ability we once had to produce beautiful architecture. As the Architect continually moves away from the idea of the Master Builder model we distance ourselves further from the knowledge and understanding that once founded our ability as experts in buildings. Architects once knew what the representation of lines on paper and the real-world implications of drawings meant to a craftsman. As designers continue to spend more time in front of their screens they become further disconnected with how the digital world becomes the physical. This relationship (computation) is disconnecting our profession from the feeling of swinging a hammer or driving a screw. Yet we face a true challenge where the computer is not only necessary in the digital age we find ourselves living but used correctly it is a true asset. We must begin to train our students and professionals how to design in digital space without losing sight of gravity, structure, assembly processes or materiality. The studio explored a series of relationships; research to practice, academia to the profession, design to materiality + prototyping and digital to physical environments. The exploration of these relationships destroyed the students understanding of what each relationship was and rebuilt their perception of each relationship.

RESEARCH TO PRACTICE

In the academic environment research is easily achieved through assignment based learning. This is not always true of the profession; budgets and deadlines often prevent time spent investigating or prototyping new ideas. Academia is training students to produce great work however it is not training them to work in groups or teams on projects. Although it is much easier to track each student's exact efforts when work is individual, this imbeds a culture of professionals who don't work well together. This trend created by Academia has to be changed, when students are asked to work together in


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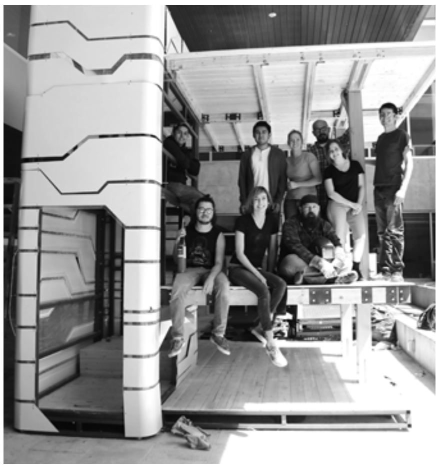
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Figure 1: Collaborative Studio

Figure 2: Toy Factory Team

Figure 3: Fairytale Team

teams they ultimately struggle with the hierarchical order which manifests in personality conflicts. This studio attempted to diminish the idea that any one singular person was responsible for any one singular design aspect. In order to test these two theories students never worked individually and the timeline for research on a team project was cut in half of what it should typically take. In the case of their first assignment they were given three weeks to produce a body of research that should normally take six weeks.

In teams students were asked to develop a body of research investigating Design for Disassembly (DfD), Design for Environment (DfE), Pre-Fabrication, Panelization, Off-Site Construction, Mass Customization, Mass Production, Construction and the Means of Production, Modularity, Transportability, and off-the-shelf components. (They were to choose a minimum of 3 from the list) This research focused on invention, materiality, methods of assembly vs. construction, prototyping, fabrication, precedent analysis, historical explorations, theoretical discourse, digital building, physical model making and experimentation. The assignment challenged the students to reframe how they perceive architecture and the way research is conducted through making, including craftsmanship, and ideas of the master-builder ideologies. They were challenge to re-claim responsibility and through the process of design become 21st century master-builders. Specifically this referred to the digital era of architecture and a renewed role including partnerships with computer driven machines and technology providing increased opportunities for the designer to take more responsibility in every aspect of architecture from design to construction and eventual remodeling or demolition. The intent of the condensed research was to inform the Thesis for their work throughout the semester. By considering how Architecture is designed, built and delivered to a site through both form and function, this research served as the driver for cohesive technology and design of objects, spaces, aesthetics, materialization and fabrication of a Design-Build project.

ACADEMIA TO PROFESSION

In order to bridge the disconnect from an Academic studio to a professional environment the class was structured to mimic a professional firm. The studio instructor acted as the principal architect rather than an instructor. They key difference is that the students are expected to already know how to produce the necessary documents, drawings, renderings rather than nurturing along the progression of their individual building project. The studio environment this created was very similar to a young firm just getting started. The first project acted as an extended interview within the firm where the principal could oversee and consider students for more advanced roles in the coming weeks of the studio. By the end of the first assignment (3 weeks) very few of the students were able to understand the research was to be rooted in the real world, or that the objects they were prototyping should be directly applicable to buildings, a disconnect often created by academia. Students are trained throughout their academic career to “research” by 3-d modeling and rendering or building small models from materials not feasible in the built environment, this causes a residual reaction when students respond to an assignment in which they do not treat the “research” as real world objects. Though the majority of final products and prototypes from the first assignment were inspiring and often amazing the studio had to spend time working an additional week on translating one or more of their projects to a more realistic output. Often times a studio would simply extend a project and postpone the next, however an office does not have that luxury and in this case the academic studio did not consider that as a possibility. The studio immediately began assignment two while assignment one was still wrapping up. Similar to the function of an office, many projects are often in process simultaneously in differing stages of completion.

The students responded well and within a week they had the first assignment off their plates in order to focus their attention on the design of two two-story playhouses. At week three of the semester the academic environment took a huge leap toward the professional setting. The studio was split in half with eight team members on each side, one Design-Team manager and one Construction Manager were assigned to each group. This “vertical” studio was structured with students from all three of the UNM School of Architecture and Planning’s academic tracks in the Architecture program; our final semester BA Architecture, second semester March II and third semester March I students. This varied level of education and experience offered a parallel to the office setting where employees are in various stages of their careers. This type of setting provides an opportunity for more shared learning and respect of others experiences and knowledge. The project and construction manager assignments offered an immediate hierarchy in the studio structure with each design team manager organizing and leading their team in design exercises and delegating duties to subgroups. As the principal of the firm in this studio setting I met with my team managers during each studio to address any concerns or questions and spent the remainder of my time split between the two groups offering insight and allowing them to consider it as a team. The students desire to have ownership of the final design was obvious from the onset despite the direction for them to work in a team setting. The first few rounds of design were clearly a result of individual pieces tacked on from a few people resulting in forms that were less that attractive. As the principal of the firm I tried several methods of breaking down the barrier of self-ownership in the project with an attempt to get them to understand the importance of the collaborative environment. This was accomplished first through design charrettes with the entire studio working on a singular project. This method was successful in defining the broad concept for each of the projects but lacked the ability to move forward with such a large group. A second attempt broke each group in to subgroups that worked independently and returned to the larger group to critique the collective ideas. The final method used for distilling the original form was for these subgroups to put all of their designs through a blind review with the entire group. This removed any issues with personality conflicts or the like and the entire group was able to select the best form to work from. Once the form was selected the groups finally began to work collaboratively. This blind process helped them understand importance and impact of collaborative design. The teams of eight finally, in the eleventh hour began to work as a unit and focused their design iterations as a collaborative group. They worked with each member present critiquing the 3-D modeling in real time. One person 3-D modeled throughout the discussion and work session (a 10 hour session) of the form and design allowing the design process to flow seamlessly by working in a collaborative environment. The design phase of the design-build project finished with a client presentation and approval to proceed with the project as demonstrated. The two teams began two weeks of documentation. Several participants from each team were selected to work on a publication while the other four remaining team members produced the construction document set for the build.

The construction document phase of the studio is not as simple as translating the design decisions on to a conventional format. This studio proved that many of the decisions necessary to build are not thought of at all in the academic setting. The construction document phase included the design and re-design of serval aspects of the projects including curtain walls, structure, lateral bracing, operable windows and many other elements that were claimed in the presentation to the client. Much of those concepts were much harder to achieve in the detailing than any of the students realized. Each of the design-build teams called on vendors for their material expertise for suggestions on how to best detail the attachment or selection of various materials.

MATERIALITY + PROTOTYPING

The students demonstrated a strong desire to use some materials that required custom detailing. In particular one team designed their curtain walls with a custom CNC milled zinc skin. This required several meetings with the distributor to discuss the various options with zinc including finishes and application. In order to discuss these detailing options the Studio Instructor brought in the rep to look at the detailing of the zinc panels. The distributor presented several methods of attachment, flat application without seams, lock style with seams, and wrapping with rear mounted clips. Through the discussion the team was beginning to discuss using a taping method and they were close to solidifying that decision when we began to discuss how those panels needed to be able to be assembled, disassembled and moved to site where they would be reassembled. The realization of material weight, application method, permanence, and durability led them to a wrapping technique with a rear mounted clip system. This solution allowed the team to quickly demount the skin from the curtain wall for safe transport multiple times.

Both teams sought help from experts on specific material selections. In two specific cases the designers struggled with cedar vs. redwood and polycarbonate vs. acrylic. The experts offered their insight in material properties, durability, sun exposure, availability and cost. The experts also disproved old notions of polycarbonate as a better solution for strength and durability. The reps explained that today's formula for acrylic far surpass the former yellowing and brittleness from sun exposure that once took place. These factors made it easy for the teams to select cedar and acrylic for their final materials based on the information the material reps provided them. In this situation the students accepted the expertise readily and were amendable to the changes these selections made to their perception of the aesthetics.

One team struggled with an aesthetic decision in which they wanted to achieve a curved corner condition using an e-panel material. In order to investigate the corner condition as both straight and curved and the team used simulative modeling as an exploration tool prior to prototyping. By 3-D modeling the conditions they were able to collectively discuss the aesthetic implication of the detailing. The team finally worked well as a unit when they were attempting to find a balance between the obvious easy solution consisting of straight corners versus the aesthetic curve they preferred. Due to their desire to keep the aesthetic curved condition they began researching through prototyping. The team first did a series of back cuts, or scores in the e-panel to see how the scores read on the exterior surface and what degree of curve was possible. Through iterative prototyping the team CNC milled and testes the e-panel achieving their desired level of curve articulation with 1/8" wide scores with a 1/8" spacing. This demonstrates the need in architecture for designers to have the ability to physically prototype their ideas in order to prove or disprove concepts. In this case the prototype was then translated directly to the construction documents for final fabrication. Due to the resolution of the detail prior to making their final decision the team had no issues with the parts or pieces in final assembly. This example is where Academia and practice diverge in their ability to conduct research. In academia we are able to produce these type of prototypical conditions in a matter of hours, whereas in the professional setting we would need to hire a fabrication to produce something as a test resulting in a dramatic loss of time and expense. This setting, where the vast majority of practices do not have appropriate model shop space, tools, or access to fabrication of equipment, including laser cutters, or 3-D printers is at best an antiquated approach. Practicing firms find themselves unable to stay in-tune with academia due to the advances in technology because they are ignorant of the impact technology has in the profession. Academia is training students to be experts in technology with respect to digital modeling, 3-d printing, cnc machines, and robotics, while the majority of the profession is so far removed from technology the talent and


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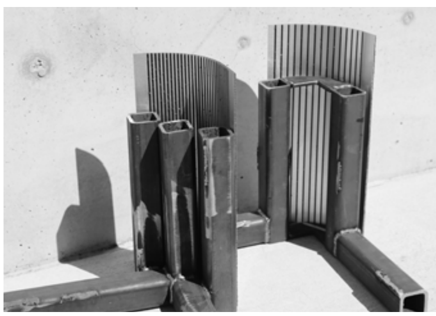
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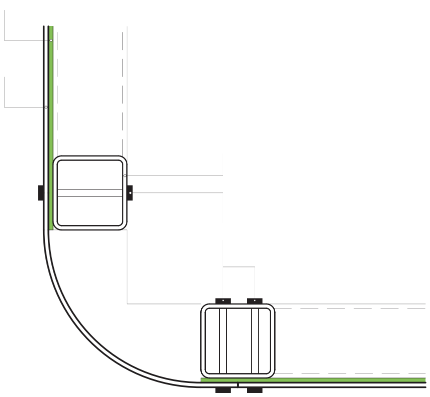
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Figure 4: Fabric Testing

Figure 5: E-Panel CNC cutting

Figure 6: Steel + E-Panel Mock-Up

Figure 7: Final E-Panel + Steel Drawing

training students received is not valued or used. This disconnect is slowing the professions use of technology and ability to conduct research within practice to a staggering halt.

DIGITAL TO PHYSICAL

While we teach students amazing technology and computational tools, academia does not show them how to translate ideas from digital concept to physical form. Academia often finds itself on the far side of the design thinking edge where beautiful renderings occupy unrealistic landscapes and structure is unheard of. This realm of academia where we go to play with design ideas unconstrained from any real forces is not simply unrealistic it is detrimental to the education of true designers who go on to work as architects. Academia must strike a balance between teaching how to use technology to produce exceptional built work. We can accomplish this through design-build situations of many scales where students are responsible for all aspects of the projects. This requires a constant dialogue between computer and physical object. This is where Academia should thrive, however technology and the digital image has watered down Academic pursuit to make objects that represent buildings, prototypes or the physical exploration of ideas. The relationship from the digital to physical in Architecture would be much more successful if students were required to me more iterative with their designs, that is; 3-d model to physical object, back to 3-d model resulting in a much better final product. Due to the relationship of the digital model the relationship to actual materials have become fractured and the rendered image carries the design regardless of its true potential as a realistic object.

> "The concept of the craftsperson is so far removed from the architectural profession, which is staggering considering we have an abundance of new fabrication technology available to us to make. The idea of craft is integral to my love of the work. I no longer want to only occupy the purely heady design realm of conceptual ideas, drawings and models, but want to balance the conceptual with the physical. The realm of the body is important, and an experience many architecture students lack. How we touch and shape materials grounds us and empowers us within the physical world, and is a lesson I have been grateful to learn this semester. My future career choices will be profoundly shaped by the lesson of the craft, and has reinvigorated my love of design."
>
> —Arch 402 Design-Build Student

This studio setting worked through digital modeling in order to create and test their prototypes resulting in design decisions through the process. The teams worked in a variety of mediums as appropriate including software, sketch, diagram and prototyping used as design tools during the collaborative process.

The disconnects between academia, practice, design and construction will soon require an overhaul in order for our industry to evolve in to something more recognizable as cohesive practice. Often, the office environment does not provide opportunities for creativity and likewise, the academic setting does not ground design in reality. As the digital age moves technology further forward, architecture falls behind and further disconnected from the reality behind the representation of each line and translation from digital environment to physical construct. This studio attempted to bridge that gap by mimicking the professional environment while maintaining the freedom of academia. This blend of academic and professional work provided a experience where prototyping pre-fabrication, modular building, DfD (Design for Disassembly), and panelization theory including on-site/off-site construction methods were explored with rigor and realism. The body of work created by this combined studio (4th year undergrad, 1st year MArch II, 2nd year MArch III) proves students abilities to design are dramatically increased through hands-on experience. Although this method of teaching in a collaborative setting is much


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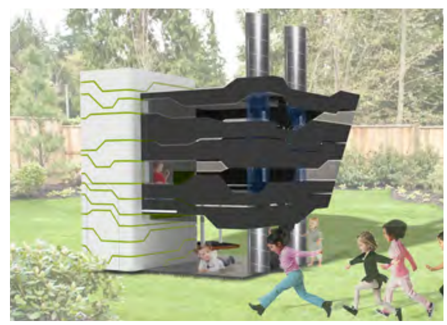
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Figure 8: Fairytale Rendering

Figure 9: Fairytale Fabrication

Figure 10: Toy Factory Rendering

Figure 11: Toy Factory Fabrication


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more difficult for the instructor, it is tremendously more rewarding for the students and the projects that arise from the endeavor. As the studio progressed through the semester the students understanding of what it takes to build buildings developed at an astounding rate. When forced to think through and apply the ideas and use their own drawings the result was palpable. One could see the transformation of the students on a daily basis, though they were not always aware it was occurring. In order for them to truly recognize what took place over the semester they were asked to reflect on their work, something Architects do not always have time for or do well.

REFLECTION

The only individual assignment done in the semester required the students to spend one week reflecting on their work. They were asked to reflect in two parts; Part 1: Select one construction method, fabrication technique, modelling/document method, or the re-design of a material choice/connection to redesign and detail. Analyzing the older condition create a comparison of the new to the former in a graphic representation. You will produce a construction document drawing(s), rendering(s) and photograph(s) of the existing condition as part of your comparison. Part 2: Reflection and Self Criticism throughout your career will help you to evolve as the best Architect/Designer you can be. Architecture should always be committed to the expansion of the research culture and supporting infrastructure in all the design disciplines. This type of work challenges many of the notions of how architects/designers should work, you have broken those “standards” and it has made an impact on you. Write a one-half to one page (no more than a page) reflection on our experience. Approach it from several viewpoints; 1. Studio Structure, 2. Reflect on your Team experience, 3. Reflect on your individual experience, 4. discuss the short term and long term impact of the Design-Build studio has had on you (talk about it’s impact on your design ability)

The reflection of the studio resulted in their understanding and realization of how far they had come. The students each spoke about their understanding of assembly, connections and materials in a much more profound way. They recognized the point at which they broke away a purely conceptual standpoint to realistic design principles that are buildable. The students understood the relationship from the conceptual realm and where it fits within the design process, and how those ideas became clearer when placed into physical practice. The clarity achieved by the studio was evident through the activity of building and it proves the Design-Build setting in education bridges many of the disconnects we face in Architecture and Design.

The second part of the reflection allowed the students to address issues that arose during or after the fabrication was complete. Students redesigned things like connections where it was difficult to fit your hand or the method of structuring the playhouses. This provided an outlet and experience for them to fully offer solutions to the mistakes made during the process. The redisgn process demonstrated to the students the need for exploring and researching through making. The Architecture and design profession has lost sight of applied research through making and building. The design-build projects in an education setting is successful at bridging the disconnect from education to practice to construction and will foster stronger and wiser Architects

Figure 12: Teamowrk

Figure 13:Material Handeling

Figure 14: Working Together

Figure 15: Assembly Progress

Applied Research: Design-Build Studio as Laboratory

A Design-Build program integrated into the curriculum of accredited MArch/BArch programs at the University of Arizona uses the vehicle of small residential projects to hypothesize and test the efficacy of various wall and roof assemblies against thermal transfer and as thermal mass.

MARY C. HARDIN
The University of Arizona

INTRODUCTION

A Design-Build program integrated into the curriculum of accredited MArch/BArch programs at the University of Arizona uses the vehicle of small residential projects to hypothesize and test the efficacy of various wall and roof assemblies against thermal transfer and as thermal mass.

Five prototype dwellings were designed, by students and faculty, for the most common residential lot configurations in Tucson; each with a different thermal strategy for avoiding summer heat gain and/or increasing winter heat gain. While some residences were under construction by a design-build studio, a series of thermal sensors was placed at key locations within the wall and roof assemblies to measure the transfer of heat. A weather station on site recorded the conditions in the immediate microcosm, and all sensors reported to a computer stationed inside the residence under study. The temperature data was recorded every 15 seconds for a full year of inhabitation by homeowners, and then conclusions could be drawn about the performance of the building envelope.

THE DESIGN-BUILD PROGRAM

A brief overview of the structure and organization of the Design-Build Program at the University of Arizona is useful to explain the ongoing pedagogical goals of the program within the architecture curriculum, the specific project discussed here, the research embedded within the project, and the method of project delivery.

Faculty members and administrators of the College of Architecture, Planning and Landscape Architecture established a corporation called the Drachman Design-Build Coalition in 2004, which was designated as a 501c3 non-profit by the IRS in 2006. This entity was formed in service of the existing design-build program in the college, which sought to design and build affordable housing for the segment of Arizona's population earning below 80% of the area median income. The objectives of DDBC included the establishment of a standard of design quality that encourages dignity and pride of ownership in dwellers, the provision of hands-on educational opportunities for architecture students to design and construct residential projects from land acquisition to post-occupancy evaluations, and the provision of opportunities for continued education for faculty in order to promote personal and professional growth and development as it pertains to service delivery and public policy. Incorporation as a 501c3 organization allowed DDBC to function as an entity separate from the University, in order to obtain a contracting license, borrow funds for construction, subcontract outside of state bidding regulations, maintain financial independence, obtain grant funding and donations, and qualify as a Community Based Design Center for the purpose of gaining IDP credit for student interns.

All of the projects designed and constructed by DDBC have been community outreach projects, delivered within the framework of a design-build studio, a curricular offering of the UA School of Architecture. Taught by a registered architect and residential contractor, these studios have exposed students to the spectrum of architectural practice, from project inception, client meetings, design and construction documents, to through the construction of each residence to completion and certificate of occupancy. Each residence has taken three semesters to complete; typically one semester spent in design and construction documents and two in construction. Completed residences are sold at cost to first time homebuyers through a HUD homeownership program with strict qualifying requirements.

RESEARCH COMPONENT

Within this educational framework of design and construction, faculty members found opportunities for research that aligned with the pedagogical and outreach goals of the design-build program. The quest to identify the lowest cost, most thermally efficient products for building wall and roof assemblies for affordable housing led to a research agenda that spanned four of the residential projects. Design guidelines for energy and water conservation were developed before design commenced on the residences, in order to guide faculty and students in decision making with regard to resource efficiency. These guidelines compared all factors known to affect energy and water use in residences in arid climates, and ranked them in terms of efficiency and cost. Using the guidelines for thermal comfort control, the residences were designed to employ insulative strategies, thermal mass strategies, or strategies that combined the two approaches (hybrids). During the design phase, each dwelling was modeled with software that simulated the building envelope and and predicted the annual energy use. During the construction period, thermal sensors were placed at key locations within the wall and/or roof assemblies, and were connected to a local weather station and computer at the time of home occupancy. Temperature, air velocity, and other measures were taken at fifteen second intervals for a year while the home was occupied by the new homeowners. Finally, the actual energy use was compared with the predictions and design revisions were proposed for each dwelling.

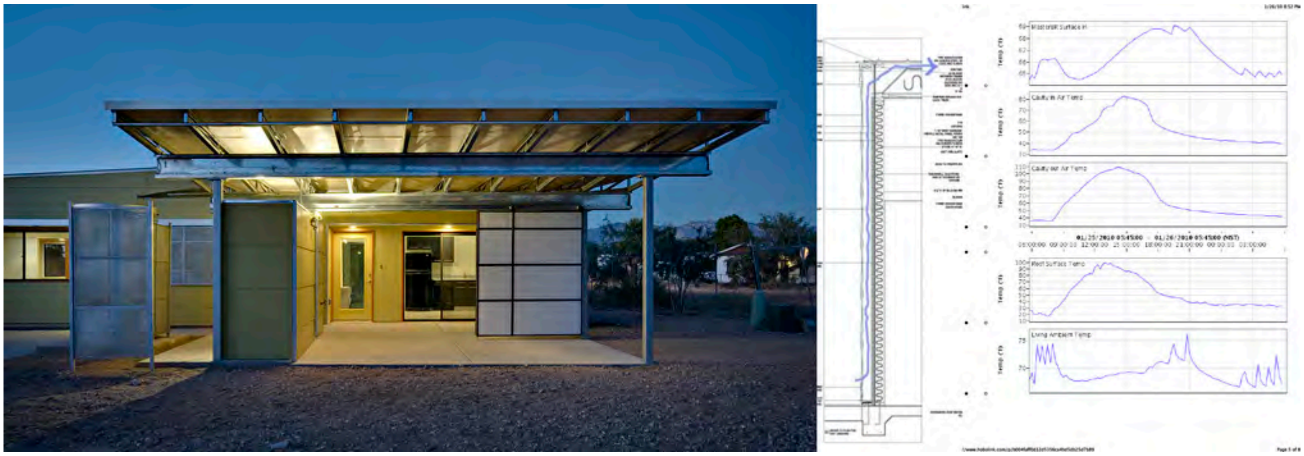
DESIGN GUIDELINES FOR ENERGY EFFICIENCY AND WATER CONSERVATION

The design guidelines that governed the development of the residences designed and constructed by UA design-build studios were compiled and organized by faculty and staff of the college, and were published as a 40 page document that ranked strategies, materials, equipment, and other factors that can affect energy and water efficiency, along with a cost index. These guidelines are available online at http: /capla.arizona.edu/sites/default/files/faculty_papers/Conservation%20Guidelines%20for%20Affordable%20Housing.pdf.

PROJECTS

Flow-Through House

The first residence in this series of five was designed with an integrated cavity wall along the entire southern façade. The cavity wall was intended to shade the exterior of the actual structural wall and also lessen the daytime heat absorption of the most exposed wall by the



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use of thermal convection through the cavity. Flow-Through House is a single story, three-bedroom house with 1072 square feet of conditioned space. The long axis of the house runs east-west, which takes best advantage of solar orientation for passive solar considerations. The wood framed south wall is designed to function as a thermal break, with a 3.5 inch cavity that is vented near the bottom and top of the wall. Foil-backed rigid insulation was layered over the exterior of the structural 2x4 wall (thus facing south within the cavity) and the exterior of the 2x4 cavity wall was clad with fiber cement panels (perforated near the bottom and top).

The energy performance of this house design was simulated in ENERGY-10 software, which predicted an overall energy savings of 5.8% with the incorporation of a south-facing vented cavity wall. The simulation showed slightly higher heating loads due to the flushing of heat from the cavity in winter months, but a significantly reduced cooling load during the rest of the year.

The inhabited house was monitored for a one year period, using a central weather station installed on an outbuilding near the residence that collected data on the microclimate, and several sensors measuring temperature and air movement around and within the cavity wall. The results of the data collected verified the design hypothesis for this residence. During the daytime in the hottest summer months, the cavity wall did act as a shading device for the structural wall (reducing the air temperature inside the cavity wall by up to 40%) and the convective air loop within the cavity brought air into the cavity that was an average of 12 degrees cooler than the exiting air. As predicted, the cavity wall did not contribute to energy savings during the cold months. If the cavity wall were redesigned with operable inlet vents, the cavity could be used for heat gain during the winter.

The total cost of the electricity used for the year the house was monitored was $965. This compares favorably to the Tucson average of $1440 per year per household. The addition of the vented cavity wall cost $80 in extra materials. The energy savings that could be attributed to the vented cavity wall for the year the house was monitored were $60,61. In less than two years, the savings paid back the cost of the extra materials.

Armadillo House

The second residence was designed as a super-insulated light gauge steel and steel panel clad envelope penetrated by small courtyards for natural ventilation. Armadillo House is a single story, three-bedroom house with 1200 square feet of conditioned space. The long axis of this house runs north-south, due to the orientation of the parcel. Because the east and west walls are best suited for insulation rather than apertures, two small courtyards were used to break up the building mass and allow more north and south facades for window

Figure 1: *low-Thru House; Insulative wall assembly with vented cavity wall section and data output.* (Photo: Liam Frederick)

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and door openings. The courtyards also allowed for natural ventilation through all rooms of the house, and therefore less reliance upon mechanical cooling. The building envelope was engineered to allow a four feet framing bay, rather than the usual two feet bay used under the prescriptive building code. This reduced thermal bridging by a significant amount, and then rigid foam insulation was installed between the face of all framing members and the metal panels that clad the structure. Blown-in fiberglass insulation as used to achieve values of R-42 in the roof assembly and R-28 in the wall assemblies.

This house was not monitored with the weather station and thermal sensors, due to a timing conflict with the use of the equipment. However, the actual energy use data (22,600 BTU/sq.ft./year in 2013 and 21,832 BTU/sq,ft./year in 2014) can be compared with the simulated energy use estimate (30,425 BTU/sq.ft./year). The energy use for this house is 60-62% of the average in Tucson, representing approximately $571 in annual savings on electric bills for this household ($868.60 per year compared to $1440 per year for a household with average energy use).

House with Light Spine

The third residence is a hybrid design that combines thermal mass with insulation. This is achieved through the use of a custom Concrete Masonry Unit (Integra Block) with wide cavities and no end webs, that is post-tensioned and filled with an expanding foam insulation. Because there are few thermal bridges in this system, the wall assembly gives a value R-25 thermal resistance. House with light Spine is a three-bedroom residence with 1200 square feet of conditioned space. The long axis of the house runs east-west; ideal for the passive solar strategy that emphasizes winter heat gain. The window and door openings were located to take advantage of winter sun angles, which bring direct solar gain to the interior surface of the exposed concrete masonry units and concrete floor slab. The interior thermal mass serves to stabilize the interior temperature of the residence, while the exterior thermal mass radiates accumulated heat back to the night sky once the sun sets. The foam insulation barrier between the exterior and interior thermal masses prevents thermal transfer from outside in. A clerestory strip of polycarbonate glazing tops the circulation corridor that runs the length of the residence, bringing northern light into the hallway and public spaces.

Figure 2: *Armadillo House; Insulative wall assembly with thermal breaks and ventilation courts.* (Photo: Liam Frederick)

This house was monitored for one year while inhabited, and the resulting data demonstrates a significant reduction in heating costs during the winter. There was little difference in thermal performance from an insulative design in the summer months, however. The interior thermal mass walls served to stabilize the interior temperature, but did nothing

3

to reduce air conditioning needs. The computer simulation of this design showed summer energy savings if the house was ventilated during nighttime hours. In practice, however, the family occupying the house did not open windows at night due to concerns about security. These results illustrate the need for other design parameters to work in concert with thermal goals (designing a secure aperture for nighttime ventilation, for example), as well as the importance of homeowner education.

Split House

The fourth residence is also a hybrid design that combines thermal mass walls with insulative walls. In this instance, the long axis of the house is north-south, making it more difficult to place much thermal mass for winter gain. The thermal mass walls are placed as the east and west walls, are constructed of rammed earth, and are 18 inches thick. They are exposed to direct sunlight for only a few hours per day, so these walls have been effective at preventing heat transfer to the interior of the residence. The north and south façades are wood framed walls, insulated to the code requirement of R-19. All of the windows and doors are grouped onto the north and south façades, and this allows them to be adequately shaded from solar gain in the summer but to receive direct sunlight onto interior concrete floors during the winter months. The split volumes of the residence also allow for some self-shading, when one offset volume casts a shadow upon the other.

The electricity used in the Split House was 7,226 kWh during the first year of inhabitation (at a cost of $926.17), and 8,308 kWh during the second year (at a cost of 1,091.91). This represents 57% of the average household energy use in Year 1, and 65% of the average household energy use in Year 2, for savings of $514 and $348, respectively.

Figure 3: *House with Light Spine; hybrid Integra Block wall system with data output.* (Photo: Liam Frederick)

Figure 4: *plit House; hybrid rammed earth thermal mass and insulative framed walls.* (Photo: Liam Frederick)

4

Trombe Wall House

The fifth house in this series of design-build research projects is also a hybrid system; this time employing an ICF system on the east, west and north with a masonry thermal mass trombe wall on the south. The ICF walls are a proprietary system called "Mikey Block" produced in Tucson, AZ. The 12 inch by 48 inch expanded polystyrene foam blocks have 2 ¾ inch sides with a 5 inch cavity that holds rebar and gets filled with concrete. The reported R-value for this system is R-28. The ICF walls are clad with Tyvek and corrugated steel panels on the exterior, and drywall on the interior.

The trombe wall is actually comprised of two types of trombe wall designs. The classic trombe wall is a CMU wall, grouted solid and faced with glass, with a 4 inch air cavity between the glass and the CMU. There are operable air vents in the CMU wall that allow heated air into the interior of the house on winter days, and close it off on warm days. There are operable vents at the top of the air cavity to allow heated air to escape to the exterior of the home on warm days. The other type of trombe wall is a glass wall with a 38 hallway between the glass and the solid grouted CMU wall. This modified type of trombe wall relies upon winter heat gain to the concrete slab floor as well as the CMU wall, and is ventilated by the movement of air through the hallway (driven by the mechanical system within the house or by the ceiling fans). The two trombe walls sit side by side, facing south, with a roof overhang that controls direct solar exposure. The classic trombe wall requires the homeowners to operate it while the modified trombe wall does not.

This house has been inhabited for less than a year, but data has been gathered for several months, but has not yet been analyzed. The expectation is that the trombe walls will contribute more to reducing heating costs than reducing cooling costs. This is a design that requires homeowner education, and depends upon manipulation of the vents to achieve the ideal conditions.

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Figure 5: *Trombe Wall House; hybrid wall system with trombe wall diagram.* (Photo: Liam Frederick)

CONCLUSIONS

The design-build program at the University of Arizona provides for more than hands-on educational opportunities and community outreach experiences for the students in the School of Architecture. It also serves as a field-testing vehicle for design hypotheses of many kinds. Some of the hypotheses involve explorations of materials and materials assemblies, cost relationships between materials and maintenance requirements, relationships between landscaping design and water use, and relationships between materials assemblies, solar orientation, and energy use. This kind of applied research differs from laboratory testing, where the small-scale assemblies are isolated from any other factors such as human use and flaws in workmanship. With the design and construction of actual dwellings that are inhabited by unique homeowners, there are many variables that cannot be quantified precisely. However, the conditions of construction and inhabitation of the design-build dwellings are similar to what happens all over the region in the production and inhabitation of standard housing stock and so allow monitoring of common circumstances – a small percentage of irregularities in workmanship that can affect the efficiency of the building envelope with regard to thermal bridging, and inconsistencies in human behavior that can affect the optimal use of thermostat settings, operable shading elements, use of natural ventilation, etc.

Preliminary evaluations of the data indicate where design improvements should be made, and when homeowner education would benefit the building performance. Recommendations developed from these data has been shared in public workshops with other residential builders, and Industry partners involved in the provision of building materials have expressed a strong interest in the results of this applied research, because they can use it to more accurately promote the value of their products and to give specific advice to architects and contractors. The City of Tucson has ownership of the approved plan sets for the prototype dwellings, and has held two public workshops to disseminate the results to builders and housing officials. Also, the design guidelines that were developed for this research have been disseminated publicly and have a potentially significant impact on collective building performance if they are put into practice for mass produced housing.

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3. Residential electricity consumption in Arizona averages 1,061 kWh/month; 12,732 kWh/year. 2015 Electricity Local, http: /www.electricitylocal. com/states/arizona/tucson/

The Campus as a Living Laboratory: Post-Occupancy Evaluation and a Digital Repository as a Teaching Tool

Buildings and landscapes reflect a hidden curriculum that powerfully impacts the learning process.[1]

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In 2013-14, the California State University system funded 23 grants on 14 campuses in an effort to spur innovation in sustainability. The funding for these grants came from leveraging $250,000 of system-wide resources slated for energy efficiency improvements towards the support of educational initiatives that bridged facilities and the academy[2]. The intent of this initiative was to inspire applied research that tied teaching and learning to campus buildings, landscapes, and infrastructure in ways that would inform future project investments related to cost and energy savings as well as sustainability practices and increase the understanding of facility performance while utilizing high-impact educational practices[3].

Cal Poly, San Luis Obispo developed two winning grant proposals under this program. The first focused on a faculty-led/student-run/industry-funded design-build research project for the installation and operations of a radiant cooling system into an existing teaching space. The second focused on a course redesign to incorporate undergraduate discovery-based research into the Bachelor of Architecture (B.Arch.) curriculum. This involved taking existing laboratory exercises in a required 2nd-year building science course in order to perform a focused post-occupancy evaluation (POE) for a recently completed LEED Gold certified science building known as the Warren J. Baker Center for Science (Baker Center). The 189,000 square foot building that served as the pilot for this study is located at the heart of the Cal Poly, San Luis Obispo campus, and was designed by the Los Angeles office of ZGF Architects LLP. It is comprised of faculty offices, wet and dry lab spaces, studio classrooms, and lecture halls. It has a long east-west orientation with the majority of the fenestration on the south facade, and a large daylit atrium space at the center with offices and labs at the perimeter of the two wings.

The specific high-impact educational practices employed in the course redesign were: collaborative assignments, field-based experiential and service learning, and active involvement in systematic investigation related to important building performance research questions. In addition, the project scope included development of a digital data repository or data warehouse that would facilitate future interdisciplinary work, not only by architecture, but for K-12, community college, and other university-level STEM/STEAM[4] disciplines.

1

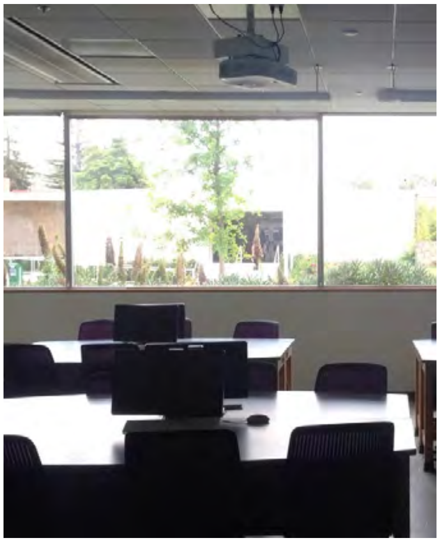
COLLABORATIVE ASSIGNMENTS

In the pilot study, students were asked to evaluate a specific aspect of building performance working in small teams of two to three persons. In these groups, they learned how to conduct a quantitative and qualitative assessment of the building shading design strategies used on the Baker Center for Science (Figure 1) and were asked to prepare recommendations for improvements based on their findings.

Using site plans, floor plans, elevations, and sections from the construction drawings (PDF's) on file at facilities planning, students were able to construct base drawings before going into the field with handheld instruments including measuring tapes, clipboards, smart phones/digital cameras, and light meters. The lab classes met four hours per week in the studio classroom, or in the field at the Baker Center for Science, with a total of 18-20 students per class. This was a supplement to the large lecture course for the 120 students that met 2 hours per week. Both settings allowed for group discussion and group work as well as instruction on relevant topics such as understanding solar geometry, reading sun path diagrams, interpreting climate data, calculating the overheated period, measuring vertical and horizontal shading angles for existing shading devices, and evaluating quantitative and qualitative aspects of sunlight entering windows adjacent to the study area (Figures 2, 3). Student teams self-selected fenestration and particular orientations on the building that they deemed most relevant to their own concurrent studio projects to study for this assignment. Results were presented in students' studio sections and discussed for opportunities and trade-offs so that they could later be further synthesized into reporting back to the design team.

In the lecture course, students were supplied supplemental background information about the project vision and goals based on a preliminary feasibility study and programming document. Because one instructor for the course had been the campus liaison architect when the study was prepared, students learned about the human dimension of the project's design process which involved capturing the client's aspirations, describing the functional and space needs of future building occupants, and grasping the basis of design established by the California State University system and carried out by the architecture, engineering, and construction team consisting of ZGF Architects LLP, Rumsey Engineering, Gilbane, and a host of consultants and subcontractors.

Figure 1: *Study areas outlined on south facade (photo credit:* Brittany App)



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IN-THE-FIELD EXPERIENTIAL AND SERVICE LEARNING

The building science course redesign also afforded opportunities for enhanced field studies leading to direct observation, measurement, and verification of building performance typical of a post-occupancy evaluation, and for interaction with the campus as a form of service learning.

By carefully selecting an on campus case study project as the focal point and then weaving various building-related content throughout the course, students were able to more readily understand both synergistic opportunities of whole building design, such as massing, orientation, shading and trade-offs with daylighting, heat rejection and contextual response. The opportunity to critically assess performance in an objective and systematic manner through instruction, while receiving design team perspectives through separately conducted interviews and anecdotal feedback from building occupants, proved invaluable. This was validated through student's self-reflections and feedback on the teaching and learning approach provided weekly via online forums indicating that overall they felt more comfortable integrating solutions within their own studio work in those topic areas evaluated in the POE.

DISCOVERY-BASED UNDERGRADUATE RESEARCH

From a NAAB student performance criteria and learning outcomes based perspective, this type of post-occupancy evaluation provides an opportunity for students to demonstrate investigative skills described in Realm A: Critical Thinking and Representation (A.3 Investigative Skills), Realm B: Building Practices, Technical Skills and Knowledge (e.g., B.6 Environmental Systems; B.7 Building Envelope Systems and Assemblies; B.8 Building Materials and Assemblies; and, B.10 Financial Considerations), and Realm C. Integrated Architectural Solutions (namely, C.2 Integrated Evaluations and Decision Making Design Process) by providing reinforcement for topics typically introduced in other coursework such as technical documentation, value engineering and other life-cycle cost related issues.

Using buildings as an investigative teaching and research tool is a longstanding if not widespread pedagogical tradition in architectural education[5] but one that can be challenging to implement due to limited contact hours for lecture or seminar classes, insufficient practice with or knowledge of post-occupancy evaluation methodologies, a lack of familiarity with or insufficient quantity of measuring equipment, and problems accessing real building data.

There have been several successful programs that aided in the development of investigative hands-on building science education for architects that have the potential for wider application and implementation across disciplines. These include The Vital Signs Curriculum Materials Project[6] funded through the Energy Foundation, Pacific, Gas & Electric, and the National Science Foundation in the 1990's and Agents of Change[7] funded through FIPSE in the early 2000's. Both were instrumental in cultivating a robust learning community of faculty, students, and practitioners who continue to share best practices and teaching resources for over 25 years. Moreover, both efforts contributed to the idea of developing of a digital resource library consisting of case studies, an image archive, curriculum materials, and more.

BUILDING A DIGITAL REPOSITORY

Generally speaking, data collected (or generated) during most architectural student projects is considered for one time use and then discarded only to collect the same data again the next time the same site is chosen. In order to create a more permanent and lasting record we envisioned that this pilot study could serve as a launch pad of instructional resources for architecture, landscape architecture, engineering, and other disciplines at a variety of instructional levels and at different institutions. As such, the idea of a digital data repository or data warehouse was born.

Figure 2: *June 10th - 9am,* As-Built Room 261 (Photo credit: Stacey White)

Figure 3: *June 10th - 9am,* V-ray Model Comparison Room 261 (Image Credit: Clare Olsen)

Building documentation that has been gathered for this pilot study provides an excellent starting point for the digital repository with the Baker Center for Science at the core. Data and documents have been drawn from all phases of the design/construction process including pre-design, design development, construction documents, and post-occupancy. A wide range of data types are represented such as the Building Information Model (BIM), Excel spreadsheets, eQuest energy models, LEED documentation, and field notes as Portable Digital Format documents (PDF's) as well as images saved as JPEG, TIFF, and GIF files. In addition, a team of instructional faculty and student assistants did their own pre-building investigations to explore potential application of digital analysis tools for representation (Revit), visualization (V-ray), and predictive vs. actual energy modeling (eQuest).

For the purpose of short-term document sharing during development and implementation of the spring course, students and faculty utilized a commercially available dropbox-style shared drive and a secure Learning Management System (LMS) for temporary digital storage of documents and data. The shared drive provided ease of file-sharing between on and off campus users (for example, faculty with architectural firms and consultants). For students, faculty and facilities staff, the LMS course shell provided secure in-house storage and retrieval capability of source documents and also served as a location for students to upload their completed assignments.

For more permanent storage, access, and public document sharing, other web collection-based tools are being evaluated for adoption such as Artstor's *Shared Shelf* or *Omeka*, a web-based, web publishing platform for collection-based research for scholarly, library, and museum work managed through common indexing standards. Other alternatives for managing archived data include *Zotero*, a bibliographic tool that allows for either remote (web) or local desktop access to reference files through an indexing system. The campus also provides a web-based portal called the *Digital Commons* for sharing of campus-authored or affiliated documents.

The utility of any of the building data and documents depends significantly on capturing a detailed description of the source documents to include their origin, authorship, date, version-control, and file formats. These attributes of the data records are referred to as *metadata* or "a set of data that describes or gives information about other data"[8] and are key factors affecting the user ability to interpret retrievable digital files in a meaningful manner.

CHALLENGES OF WORKING WITH REAL CAMPUS BUILDINGS

While the pilot study provided excellent opportunities to launch building investigations for faculty and students, it was not without its trials and tribulations. For example, it took the instructional team over one year to receive building energy data files from facilities services. In addition, some data is password protected and can only be made available to students on a limited duration. Field work conducted in snapshots may lead students to incorrect conclusions about building performance and needs to be carefully judged. Assignments archived with uncorrected information may be misinterpreted at a later date. The list goes on. All of these items will be taken into consideration as the project is evaluated for future iterations.

From the design side, willingness to open facilities to performative assessment can be challenging, as some firms may consider critical assessment exposure to avoid. However, we found that the project team -- architects, engineers and consultants as well as the campus management and leadership personnel, were willing participants. In particular, ZGF's culture of reporting and self-assessment as well as improvement is both understandably rare and was critical to project success.

CONCLUSION

The objective of this pilot study was to redesign existing coursework in ways that would engage students and faculty in the investigation of environmental performance "in their own backyard." Our team tapped the potential of post-occupancy evaluation methods in order to activate high impact educational practices (such as collaborative assignments, experiential and service learning in the field, and discovery-based undergraduate research). At the same time, the pilot created an opportunity to facilitate further teaching and research opportunities on campus through the development of a digital data repository or data warehouse. The warehouse will be built upon the various data and documents related to the whole building life-cycle (from pre-design through occupancy), and will include the results of academic research and field studies as new data types thereby perpetuating the teaching and learning cycle.

The project illustrates the potential benefits of using campus buildings (and sites) to improve student learning through engagement, ignite new collaborations for faculty interdisciplinary research and teaching, and strengthen the connection between facilities and the academy while promoting environmental change.

NEXT STEPS

Within the realm of high impact educational practices, there are many more dimensions to student learning that can be explored through the Campus as a Living Lab initiative in general and the Baker Center for Science in particular. This includes enhancements and refinements to those attempted, and new areas ripe for development that relate to student and faculty forays into building and site performance research. In total, the range spans from community service learning, curriculum development university-wide including STEM/STEAM disciplines, first year seminars, writing intensive courses, collaborative assignments, diversity learning, and capstone projects in the future.

We look forward to completing future investigations focusing on assessment of student learning outcomes; investigating additional building science topics such as thermal comfort, mechanical systems, acoustics, and water use; and, exploring the boundaries of collaboration between architecture and engineering, art and materials science, chemistry and horticulture, and so on, to bring together the diverse epistemologies and academic disciplines with the Baker Center serving as a hub. In the words of Clare Olsen and Sinéad MacNamara, "Creative moments occur when making connections across boundaries, what's commonly referred to as 'thinking outside the [disciplinary] box.' Conversations with others outside one's discipline, approaching problems from a new perspective, and the propensity to fuel game-changing, insightful, exhilarating revelations."[9] What better educational setting than the campus as the living laboratory as a stage for collaborative learning and discovery-based research that builds upon one's direct experience in the built environment.

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Testing Whole Building LCA: Research and Practice

Environmental Life Cycle Assessment (LCA) can be used to evaluate the environmental impacts of a building resulting from manufacturing, construction, operation and maintenance and the end of life demolition and disposal/re-use. Tracking impacts such as greenhouse gas emissions and smog formation, LCA can enable comparison of building proposals testing options of material use, system selection and system performance.

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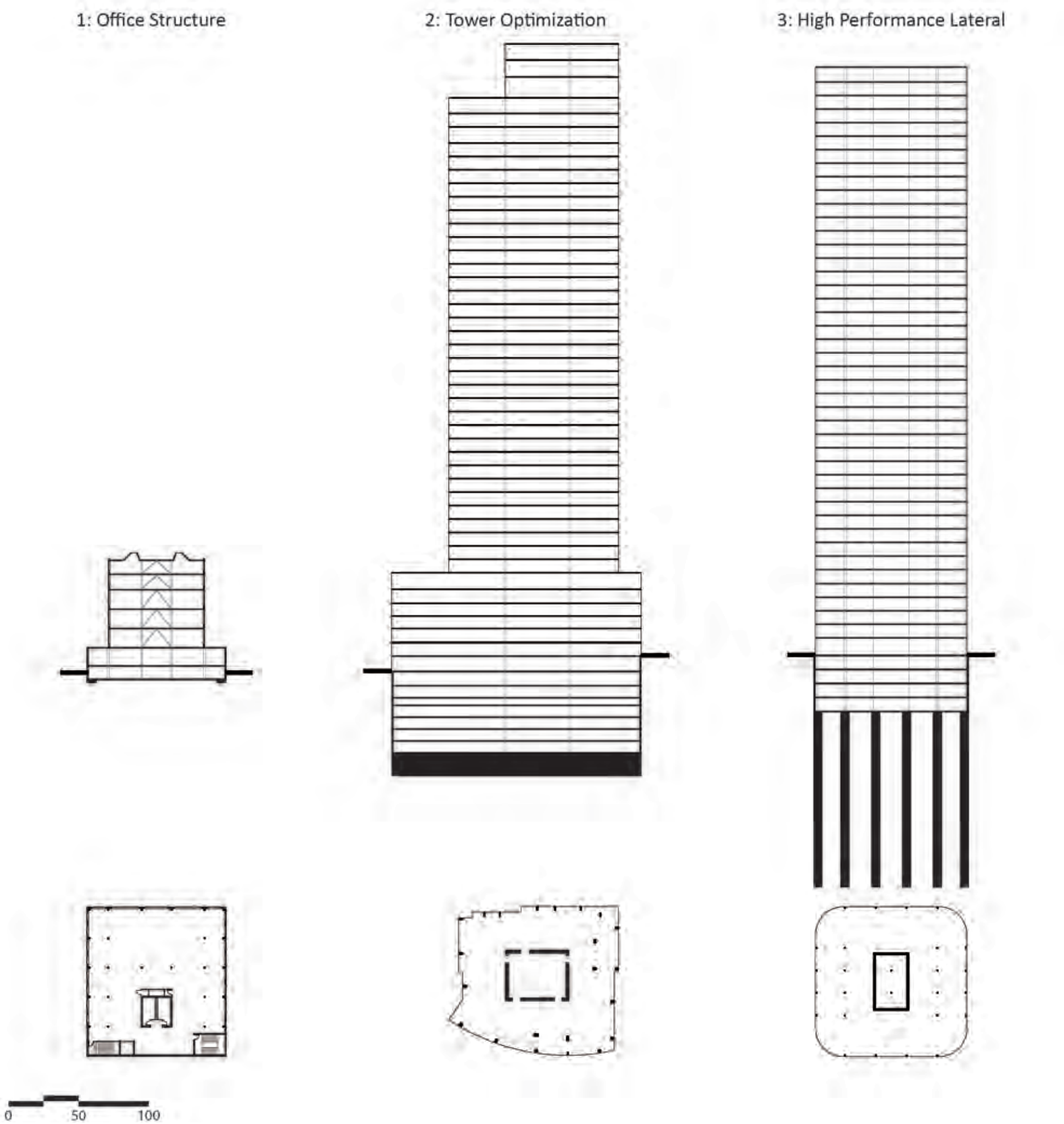
Green building programs such as the U.S. Green Building Council's LEED V4 rating system (USGBC, 2014), the Living Building Challenge (ILFI, 2014) and the International Green Construction Code (IgCC) (ICC, 2012) have included whole building LCA as a method to evaluate the environmental impact of buildings. These programs provide varying levels of guidance on how to perform the requested LCA and all require significant interpretation in order to implement. While the number and type of LCA tools designed for architects and engineers to use in developing whole building LCAs are expanding, these tools have different strengths and weaknesses and users have few appropriate resources for evaluating which tools to use and how best to use them when conducting whole building LCAs.

An industry-academic collaborative research effort, the Carbon Leadership Forum (CLF), founded in 2009 and hosted by the University of Washington includes a diverse group of professionals (architects, engineers, contractors, material manufacturers, LCA practitioners and industry trade organizations) advancing research to support the use of LCA data and methods within design and construction practice. One of the CLF's current research projects is to conduct whole building LCA case studies of buildings conducted in collaboration with design and/or construction teams to test the application of the whole building LCA credits in LEED V4 and the IgCC. This research funds graduate and undergraduate architecture students to be trained in LCA practices and is conducted in collaboration with the design teams.

Three LCA case studies have been completed (as represented in figure 1), each of different project types and each in collaboration with different project representatives. The research tested different LCA tools and evaluated design alternatives in an attempt to quantify a reduction to the building's overall environmental impact. The methods and preliminary results of these LCAs is presented here along with commentary regarding the potential and challenges of integrating whole building LCA and green building rating systems.

The focus of all three studies has been identifying methods to improve the environmental performance of the structural system in unique ways: case study one compared the use of different structural materials, case study two looked to optimize the concrete structure



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through the reduction of quantities and judicial specification of material, and case study three explored the environmental benefit of providing structural and non-structural systems that perform well in earthquakes. Case studies one and two both use process based LCA while case study three uses economic input output (EIO) LCA.

BACKGROUND

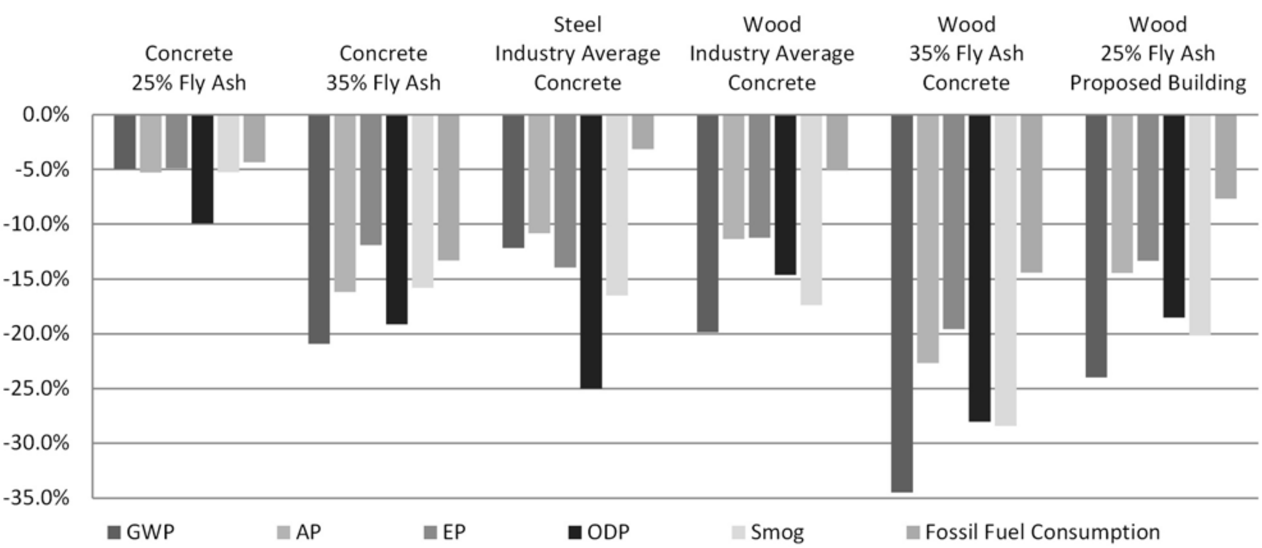
While many studies have used LCA to compare different buildings and building systems (e.g. Guggemos and Horvath, 2005 and Robertson, Lam and Cole, 2012), no published documentation of LCA studies completed to support certification by a green building rating system have been found. Different rating systems have integrated LCA into their metrics in slightly different ways. The IgCC (ICC, 2012) and LEED V4 (USGBC, 2015) both award 'points' for projects that demonstrate an improvement as compared to a baseline or 'reference' building.

Figure 1: Three Case Study Building Plans and Sections

The Athena Institute has prepared a guide for conducting whole building LCAs (Athena, 2014) that outlines the specific differences of these programs and provides some guidance regarding application of whole building LCA. For this research we focused on attempting to achieve the LEED V4 criteria that requires a 10% reduction in a minimum of three impact categories (one of which must be global warming potential/CO2e emissions) and no more than a 5% increase in any of the other tracked impacts. The Living Building Challenge (ILFI, 2014) requires owners to purchase carbon offsets to account for the embodied carbon in the building: LCA is presumed to be the method to calculate the carbon impact.

CASE STUDY 1: OFFICE BUILDING STRUCTURAL SYSTEM

A 50,000sf, net-zero water and energy, office building in the Pacific Northwest was evaluated using different LCA tools and datasets. The plan and section of the building is shown in figure 1. For the LEED V4 test, the reduction in environmental impact by building the top four floors out of heavy timber wood was compared to a more conventional concrete structure. The goal of this study was to compare the LCA impacts for conventional concrete and wood as well as both schemes with high cement replacement in order to understand if switching to wood construction would be an adequate measure to demonstrate the 10% improvement required by LEED. For this study, the scope of the LCA included the structure (foundations, basement, gravity and lateral system for both the superstructure and penthouse structures), enclosure and interior partitions of the base building 'core'. The impacts related to tenant improvement, operational energy use, water use, MEP systems and site work were not tracked in this evaluation: this is a net zero energy and water building and these components are not required by LEED. The Athena Impact Estimator (Athena, 2014) was used to both estimate material quantities and determine the LCA impacts. A life span of 100 years was used for this study and the primary LCA stages (materials and construction: use, maintenance and replacement; and demolition and end of life) were included.



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The LCA results, presented as a percent change from the baseline building (concrete slab using industry average concrete mixes) are summarized in figure 2 below. Of note, the 10% reduction could be met building the structure out of concrete (with high cement replacement), steel or wood. The building as proposed, has a nearly 25% reduction in Global Warming Potential. In this case the analysis was completed after the building was built in consultation with the owner's representative and with input from some of the sub

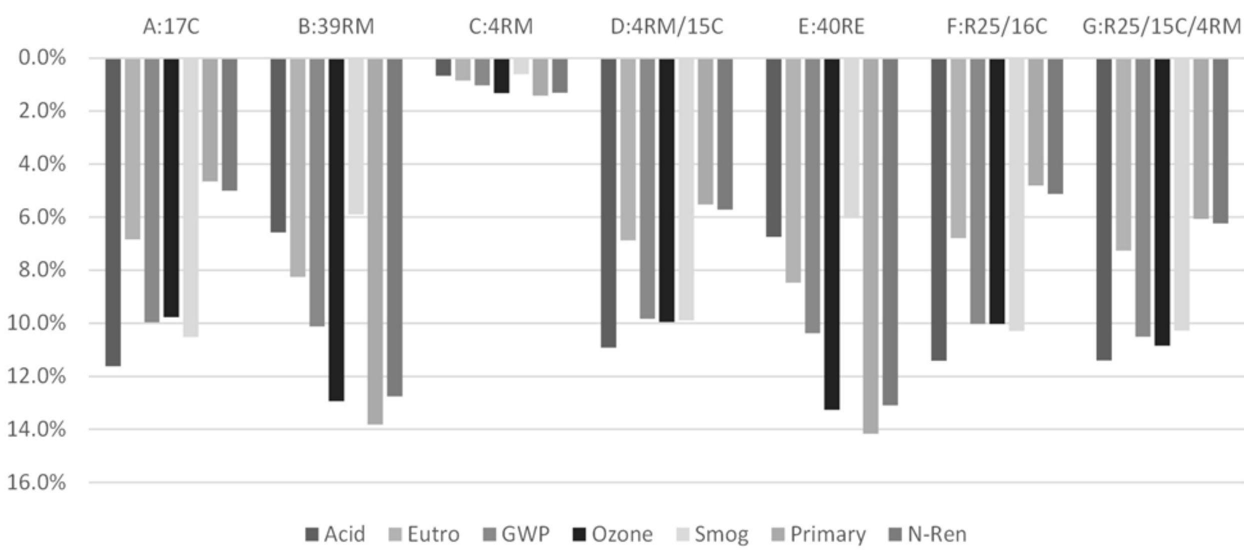
Figure 2: Comparing LCA results of structural options to baseline concrete building

contractors. Additional LCA studies were completed that will be presented in future papers evaluating issues such as the impact of MEP/PV systems, the impact of long lifespan buildings and the durability of components and the variability resulting from different tools and users on the total embodied impacts of the building. The more comprehensive LCAs were also used to predict the total building carbon footprint for Living Building Challenge certification.

CASE STUDY 2: OPTIMIZING MATERIAL SPECIFICATIONS

This study was initiated by the general contractor (Sellen Construction) and structural engineer (Magnusson Klemencic Associates) who were interested in evaluating their current practices (which already included specifications that result in lower impact concrete and reinforcing steel) relative to the LEED V4 credit and to explore if conducting an LCA and setting targets can help to influence the final purchasing decisions. This project is currently finishing up the construction documents and selecting major subcontractors. The goal of this study is to target environmental improvements that would meet the LEED v4 Whole Building LCA credit through changes to specifications and detailing without impacting costs. The LCA scope included structure and enclosure and excluded interior partitions and construction.

During the design stage the research team recommended: using the regional industry average (RIA) concrete mixes (NRMCA, 2014) and reinforcing steel with impacts reduced from the industry global average data to represent local sourcing for the project baseline/reference building. The team identified three potential strategies to achieve the 10% reduction to the RIA reference baseline:



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1. Collaborate with concrete supplier, design and construction team to optimize mix designs to meet performance and constructability requirements at lowest environmental impact;

2. Reduce the quantities of reinforcing steel required through the use of terminators and couplers instead of splices and hooks and the use of high strength reinforcing steel; and

3. Sourcing reinforcing steel from the local Nucor plant, which is powered by the low carbon Seattle City Light electrical grid.

Figure 3: Reductions in total GHG emissions as compared to RIA for different structural strategies

The maximum benefit of each of the reduction options is noted in Figure 3:

A. 17% reduction in cement from RIA (17C);

B. 39% reduction in rebar materials quantities (39RM: not feasible);

C. 4% reduction in rebar quantities (4RM: practical, but not sufficient);

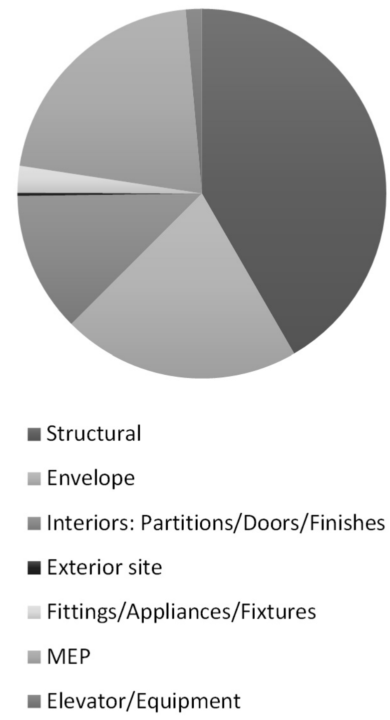
D. 5% reduction in rebar quantities (5RM) and 15% reduction in cement (15C);

E. 40% reduction in rebar electrical impacts (40E);

F. 25% reduction in rebar energy for baseline (R25) plus 16% reduction in cement;

G. R25, 15C and 4% reduction in rebar materials (4RM).

In order to demonstrate a 10% reduction from this baseline (as required to meet the LEED v4 credit), the team recommends working to optimize reduction of cement within the concrete and rebar quantities through alternate detailing practices. The design studies found that the 10% reduction can be met with modifications to structure (reducing cement use by 15-17%, reducing steel quantities by 0-4%) when compared to a reference building of the same size and configuration built using regional average concrete mixes and typical rebar detailing. Based upon this study the research team recommends: using the RIA concrete mix coupled with the R25 rebar energy reduction as project baseline; do not look for 'credit' for using locally sourced/low impact rebar as that is the current state of practice; and working with the design and construction team to optimize reductions of cement and rebar with options F and G as potential targets.



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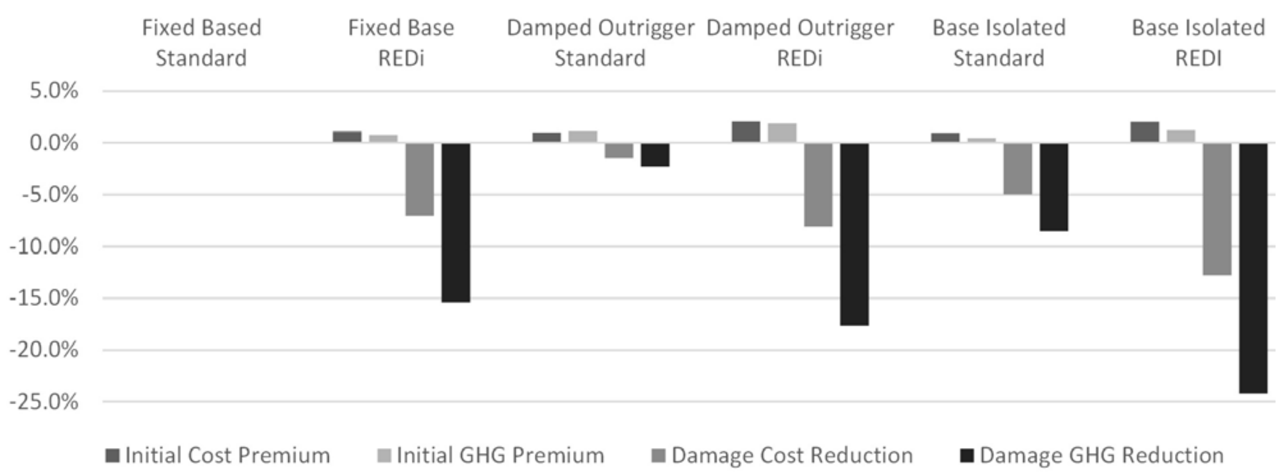

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CASE STUDY 3: HIGH PERFORMANCE LATERAL SYSTEM

The San Francisco Office of Arup had previously conducted a study of the seismic performance of a prototype tall residential tower comparing different structural systems and performance targets (Almufti et. al, 2015) using probabilistic performance based seismic design. For this study we used Economic Input Output LCA to evaluate the cradle-to-gate impacts of initial construction and seismic damage (Simonen et. al, 2015). Based upon this study, the contribution of individual components to the total initial embodied impacts is represented in figure 4.

Three different lateral systems (fixed base/standard, damped outrigger and base isolated) were each evaluated for two different non-structural component performance metrics (standard detailing and enhanced detailing meeting Arup 'REDi' standards). Each of the

Figure 4: Initial Construction GHG Emission Breakdown (Total 90M kg CO2e)

Figure 5: Environmental 'cost' and 'benefit' for different performance levels as compared to baseline initial

schemes were analyzed using a probabilistic performance based design method developed by FEMA (FEMA, 2012) that estimates damage to both structural and non-structural components (The damage for the typical design level earthquake (475 year return period) was evaluated and mean damage to components estimated and translated to environmental impact. The differences in environmental between the standard and highest performing scheme were nearly 25% as outlined in figure 5.

Although this study indicates that higher performing buildings can reduce the environmental impact of seismic damage by more than the 10% required by LEED, the results do not reflect the statistical likelihood of damage over a set time period. Although the FEMA methodology does provide guidance on how to achieve annualized damage impacts, conducting this added level of analysis is beyond the scope of most practitioners.

DISCUSSION

Life Cycle Assessment is being integrated into green building rating systems as a method of quantifying the environmental impact of material choices beyond the proxies of 'recycled content' and 'locally sourced' that may, but are not guaranteed to, reduce the impact of material choices. In each of these case studies academics and professionals collaborated to identify areas of potential improvement based upon their knowledge of building material manufacturing and production. In all cases the key opportunities for reducing the impact of building structures (switch to wood, use less cement, use less material overall and use energy efficient materials) selected by the design team were confirmed by the LCA. The rating systems reward LCA results that demonstrate improvement from a baseline building. Identified challenges include: defining the baseline building, equally weighting different impacts and the need for better LCA data on building materials and products.

Defining what is an appropriate baseline building is challenging, as it is not typical to have two fully developed designs to chose between. Selection of the baseline building will impact the opportunities and challenges in developing a final design that demonstrates significant improvement. For example, the more that is included in the baseline building (partitions, interior fittings etc.), the harder it will be to demonstrate a 10% reduction. For systems such as reinforced concrete, estimating the total quantities of reinforcing steel is a difficult and uncertain process for the design team to complete.

In one of our early iterations, one option had over 20% reduction in global warming potential and over 5% increase in eutrophication. This appears to have been generated by an error in the LCA dataset used by the whole building LCA tool (since corrected), however this highlighted an area of concern: if impact reductions in some categories are substantial, is it appropriate to negate the value of significant reductions of impact in multiple categories if one impact category shows increases of more than 5%. There does not appear to be a scientific justification for the 10/5% thresholds and question their applicability. In particular, ozone depletion is no longer an area of significant concern as the emissions have been greatly reduced due to prescriptive requirements of the Montreal Protocol (UNEP, 2007). A 5% reduction of a VERY SMALL impact is not significant. We are exploring the use of different weighting schemes such as developed by NIST (NIST, 2010) and EPA (EPA, 1990) and believe weighted impact reduction may be a more appropriate measure for use when assessing whole building LCA credits in green rating systems.

Some building industry trade groups, such as the National Ready Mixed Concrete Association, have published LCA results for a range of products and that represent industry variation (NRMCA, 2014). Other industries are still developing data meaning that we must rely on a range of LCA data sources such as global average numbers. As noted in case study 3, there are opportunities to reduce the impact of materials such as steel by selecting

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suppliers with energy efficient manufacturing processes and using lower environmental impact energy sources. At present, the opportunities to select between materials of the same type are limited and better product specific LCA data is needed.

CONNECTIONS BETWEEN ACADEMIA AND INDUSTRY

This research is founded upon connections between practice and the academy. In the process of developing these whole-building LCAs the academic and professional teams have been exploring the opportunities for integrating advanced environmental analysis into practice. The research conducted by graduate students has provided a platform for developing the knowledge and expertise within the student body to integrate LCA into academia and practice. Five students have integrated LCA into their thesis projects over the past two years. Projects such as these have been integrated into a seminar: Life Cycle Assessment for Architecture in which students develop projects in parallel with current whole-building LCA research. This term students are exploring the opportunities for tall wood structures in commercial construction and developing LCA studies to quantify the difference as compared to conventional construction methods.

CONCLUSIONS

Whole building LCA shows promise for evaluating and motivating lower impact buildings. Better LCA data, guidelines for conducting whole building LCAs and databases with a large quantity of reference buildings will be needed in order to accurately assess the actual improvement a specific building can provide compared to 'typical' conditions. However, we found the knowledge gained when conducting the LCAs and the questions asked when conducting the results to be of high value, increasing our understanding of both material specific and building system impacts. Therefore, we do not believe that the limitations of LCA should be used as an argument against its adoption rather through adoption, we expect to attain the better data, tools and benchmarks needed to improve its accuracy and effectiveness.

ACKNOWLEDGEMENTS

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Apparatus X: Designing an Architecture for Civic Engagement

Typically defined as one who uses design as tools for political change, immediate response, and/or design-as-reaction, an activist architect can be more simply described as one who takes architectural practice with him/her, commits to a community, and engages with that community's building needs – as rejuvenation, or in more extreme cases, as response to disaster caused by war, weather, or economics. These informal situations (outside of the realm of normal procedure) call for Activist Architect to be nimble, resourceful, and responsive (qualities of activism), but how does formal and informal knowledge, professional training, and experience – embodied and transmitted through the architecture – get to communities in need in order to effect change?

Perhaps the answer to this question requires design. Apparatus X is a mobile design/construction studio developed to facilitate the essentials of architectural activism: responsiveness, tools/transmission, and the establishment of relationships where knowledge sharing, design and engagement occur.

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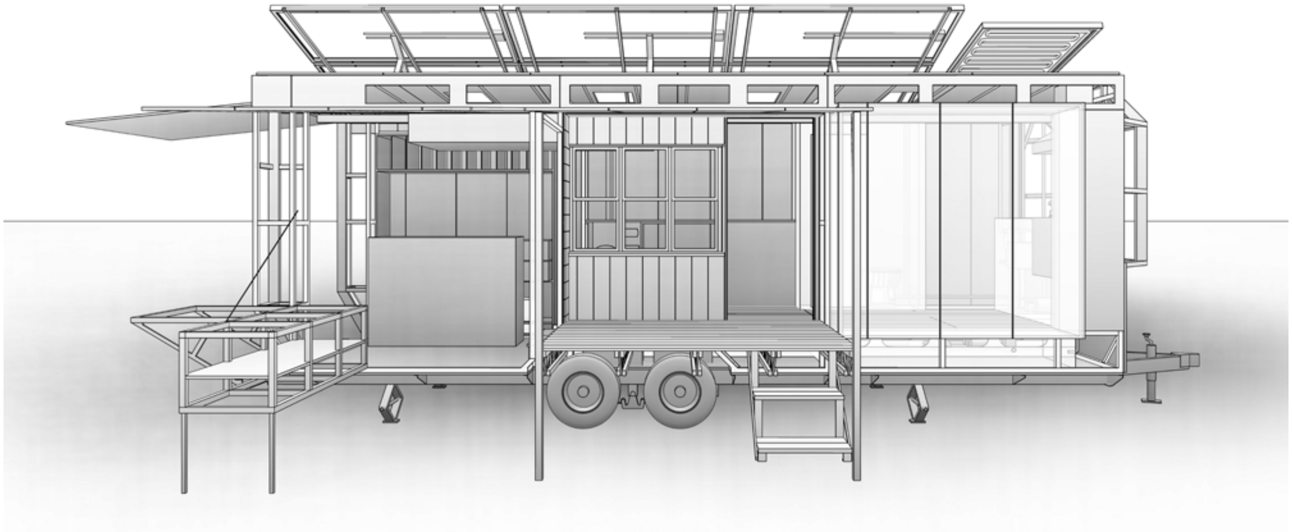
ENABLING CIVING ENGAGEMENT AND ARCHITECTURAL ACTIVISM

The profession of architecture has a long history of advocating for the architect's participation in civil discourse, public interest architecture, and activism. The architect has the ability to contribute meaningfully to complex situations of the modern world regarding housing disparity, changing building paradigms, and limited resource availability through design thinking and creative works, but such activity is often considered marginal within the field of architecture. As design-build and community outreach have expanded the profession toward the realm of complexity, 'fuzzy logic', informal settlements, and new types of urban morphologies[1] architects have drifted away from the office environment into academia, the Fine Arts, woodworking, fabrication, and other crafts as means of realizing the full value of their design thinking beyond the boundaries somewhat arbitrarily set by the profession of architecture.

While architecture acts as a profession for community engagement, within the profession there is actually a limited amount of support; politically, financially, and structurally, for the work of the activist architect. In response to the call for support of a marginalized, but impactful practice of architectural design in areas of desperate need, an alternative



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engagement strategy is proposed - an architectural activism that is tied to direct community engagement and reciprocal design, and proposes a multi-function tool/workshop/office designed specifically to activate the activist. Apparatus X, the design/build project, is an attempt to prepare an activist architecture for effective engagement outside the realm of normal architectural procedure.

Apparatus X is a self-sufficient unit that acts as an adaptable tool trailer, mobile design studio, and micro living unit designed to take architectural activism to people who need help in rebuilding after conflict, natural disasters, or catastrophic failures in infrastructures that support housing (such as financial, or governmental). It is a project that is not just about design-build, but social engagement and action.

THE DISCOURSE OF ARCHITECTURAL ACTIVISM FROM WITHIN THE PROFESSION

In the existing discourse of architectural activism, there are a series of definitions and terms that help to identify the roles, duties, and interests of a civically engaged architect – referred to as the activist architect.

As evidenced in the collection of work in their book *Expanding Architecture: Design as Activism*, Bryan Bell and Katie Wakeford identify the **public interest architect** as one who makes a career as an architect serving those who need the most help, is fully dedicated to public service work while still making a living, and is engaged in their communities. The public interest architect is also entrepreneurial, and applies design skills and architectural ideas to problems previously considered the exclusive domain of public health officials, environmentalists, and community activists.[2]

In 2008, the AIA Board of Directors passed the ***Citizen Architect*** *Resolution*. This document aimed to establish support and advocacy for civically engaged architects that "serve" their community. Through this document, the AIA commends engagement with local, state, and federal issues, gaining appointment to boards and commissions, and those who advocate for higher living standards, the creation of livable, sustainable communities, and the greater public good. They also state in the document that the AIA believes that these members should be actively supported at all levels of service.[3]

The **Development Activist**, according to Sumita Sinha, works in a world defined by rapid change and scarce resources, responding to a complex and chaotic world while making meaning of it and proposing solutions. In her book *Architecture for Scarce Resources and*

Figure 1: *Apparatus X, Expanded side view,* (Rendering: Aaron Wertman)

Rapid Change, Sinha describes an architectural activism that requires development skills, fundraising abilities, management skills, reciprocal design practices, itinerant practice, hyper-resourcefulness, self-motivation, and self-reliance.

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Roberta M. Feldman defines **Activist Practice** as "The act of architects leaving the office, engaging the community, and seeking a need for design in that community, rather than passively waiting for clients to come to them."[4] This notion can be explored through Sinha's concentric circles of design analogy (Fig. 2). The desk architect traditionally practices in the innermost circle – the safe place of "the office" with a few wealthy clients. The next circle contains development activists working in areas such as infrastructure, community projects or social housing and interacting with housing associations and local government bodies, but projects are managed in a tight sequence. The outermost fringe is the larger world of chaos and complexity – the area of 'fuzzy logic', of 'soft' information and data, of informal settlements, new types of urban morphologies such as the code-resistant megacity, of sustainable development, culture, etc.

As the profession expands and evolves, architects continue to drift towards the fringe, but find financial and political challenges to implementing and sustaining effective engagement practices. Apparatus X intends to allow the architect to flow freely across this boundaries while still providing an effective service.

ACTIVIST ARCHITECT FOREFATHERS - VOICES OUTSIDE THE BOUNDS OF THE PROFESSION

In addition to the existing discourse from within the profession, there are a few "activist architect forefathers" that help to inform/influence the definition of architectural activism from outside the bounds of the profession.

Kim Jae-kwan decidedly introduces himself as an ex-architect to make clear his newly defined role and intentions. After conducting the 'Daily Architecture Office' program, in which architects opened their doors to the public to offer consulting and design dialog, Kim decided to use the skills, knowledge, and experience he developed in dealing with the design and construction process, to create a more meaningful, helpful, and intimate connection with homeowners by transitioning from the role of architect to home repair man and woodworker. With a more engaged social presence, sound architectural design and building skills, and the capacity to build informal and formal relationships to both the community and the profession, Kim's value, effectiveness, and happiness have all improved.[5]

Using the beauty of found materials, **Martin Kaltwasser**, along with his partner Folke Köbberling, create interactive pieces of architectural work in public spaces. These works generate interaction and community dialog while not explicitly prescribing their use. This activist architect has stepped away from traditional architectural practice to engage in a dialog of radical material reuse and positive social change through self-built architecture.

Samuel Mockbee turned to academia to develop an active and engaged approach to provide architecture to people in need in his own backyard of Hale County, Alabama. His response is driven by the moral obligation that Mockbee believes is inherent to the profession. Through the Rural Studio, Mockbee provided students with an immersive experience in a project scenario that amplifies the feeling of moral obligation and a spiritual nature of architecture. Mockbee placed an immense amount of responsibility on the shoulders of the students, prompting action, intuitive decision-making, and responsive design solution that are immediate and effective. The Rural Studio offers an environment of education through experience - a valuable and typically more effective strategy.

Figure 2: *Concentric Circles of Design,* (Diagram: aron Wertman)

CHARACTERISTICS AND INFLUENCES THAT SHAPE THE ACTIVIST ARCHITECT

Informed by the definitions and examples around the existing discourse, there are a series *of characteristics and influences associated to Humanism that must also shape the attitude, thoughts, character, and skillset of the activist architect:*

EXPERIENCE & IMMERSION: *Direct exposure vs. "Visits" (including digital exposure)* - Direct exposure and immersion in a community, in which one becomes a neighbor in that community, makes community problems and concerns your problems and concerns. It turns the architect's solutions (so often "delivered" from a removed position) into our solutions (as a community). This immersive and inclusive condition is not generated from site visits and client meetings (including community or "town hall" meetings).

COMPASSION, SYMPATHY, LOVE FOR FELLOW MAN: *Extrinsic vs. Intrinsic motivation; Moral; Spiritual obligation; A return or emphasis on ethics tied to real work* - Extrinsic motivations arise from outside of the individual and often involve rewards, while intrinsic motivations arise from within the individual and involve personal fulfillment, satisfaction, and happiness. As informed by the case studies, activist architects seem to blur the lines between the two, resulting in a hybrid motivation that involves the physical production of an architectural work and the happiness associated with it from both the community member and the architect.

These factors are human nature, and a social value that we teach by example. Despite religious and spiritual connections to these factors, they are more directly informed by experience and immersion (previously mentioned) with people and the development of relationships that draw these qualities out of all of us. It is dependent then on the individual to retain the value and in turn translate these feelings to action.

A CHANGE IN VALUES: *Market forces (capitalistic) vs. People; Relationships; Community; AND the changing realm of architectural practices* - 1 – Change in value system (from the eyes of the activist architect) - FROM: a perspective that emphasizes monetary value, serving a clientele, both individual and corporate, that has the wealth to pay for architectural services and specialized design TO: a perspective that values the quality of life and provision of basic needs particularly shelter, that all individuals, rich or poor deserve.

2 – Change in the value of the architect as a professional in the design and construction processes - Architect was once one of the four titles that actually defined the term "profession" with the other three being doctor, lawyer, and clergy. Even further back in history, the architect was the "master builder" literally defined as such: arkhi meaning "chief" and tekton meaning "builder, carpenter." Today, as cost efficiency and energy efficiency continue to rise as primary drivers for building design, the value of the architect has unfortunatley become more and more marginalized.

HOLISTIC THINKING: *The big picture; The ability to step outside to see it* - It can be argued that this notion is something all architects should be able to do. However, the ability to step into the community dialog/mind/framework, while offering a holistically-minded perspective – especially in the case of a community project where there are numerous stakeholders and various levels both horizontally and vertically – enables the activist architect to understand the areas/goals that can be most effectively impacted, as well as the stakeholders that are affected by (and can affect) each aspect of the big picture. This skill also illustrates the type of inclusive relationship that an activist architect has to his/her community.

ARCHITECTURAL EDUCATION: *Formal (NAAB-centric) vs. Informal (experiential; volunteer)* - In addition to the formal education provided by NAAB-centric university programs which develops valuable architectural and visual communication skills, participation in things like charities, church organizations, youth groups, and volunteerism provides immersive experiences, informal education, and helps to build intangible skills – commmunication,

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relationship-building, compassion, sympathy, understanding, holistic vision, progressive dialog, character growth. Despite similar informal notions that are presented and experienced through immersive design/build programs like Mockbee's Rural Studio, neither academic community engagement projects, nor alternative volunteer experiences provide a community driven framework where solutions are generated through reciprocal design dialog and a grassroots, community owned strategy for progress.

ARCHITECTURAL ACTIVISM MANIFESTED IN APPARATUS X

Informed by the existing discourse, exciting practices outside of the profession, and the essentials of communal work, we arrive at a definition of an activist architect that is:

- Itinerant
- Mobile
- Embedded
- Practices reciprocity in design
- Encourages self-progressive thought and action
- Possesses many comprehensive skills beyond design
- Responds nimbly to adverse conditions
- Is a community member, a neighbor, a friend
- Has the ability to cross the thresholds of the realms of the profession
- Offers compassion and understanding
- Practices sound judgment and professional etiquette
- Listens as well as speaks when called upon to do so, and
- Can holistically contribute to communities in need.

This idea manifests itself in Apparatus X conceptually, physically, and through the ethos of the project execution.

This project does not propose a structure/framework for professionals to drop what they're doing and embed in communities, but it does present a potential solution to the question: How does formal and informal knowledge, professional training, and experience get to communities in need in order to effect change? It creates a tool, and essential spaces, that ultimately form a manifestation of the activist architect, called Apparatus X.

Through an embedded physical presence in the community, it makes the architect, and the profession of architecture, directly accessible to those who need architecture's

Figure 3: *nbuilding and Learning,*
(Photo: aron Wertman)

skills, knowledge and sensibilities, rather than relegating community engagement to a marginal practice. With a prepared physical presence, the activist architect can engage in design activities and tasks WITH the community rather FOR the community. In this way, there is reciprocity in learning, designing, and building that provides local knowledge and direct feedback to the activist architect, creating an environment of effective design and engagement for the betterment of communities and individuals in need. Apparatus X and the type of engagement it supports are not simply about participatory design, but rather responding to the needs of an individual on both a temporal and a metaphysical level. At the core of Apparatus X lie the principles of education through experience, tooling and building as empowerment, and an attitude of self-progressive community activism.

Apparatus X advocates an embedded presence in the community, grassroots community generated interventions/solutions (inside-out instead of outside-in), reciprocity in design dialog (it's never a project delivery scenario), collective knowledge (local knowledge and direct feedback), and empowerment through building/tooling.

For me, as a student of architecture and a person who has been involved in community re-building, Apparatus X is a tool of anticipation – a tool designed for engagement; a tool prepared to address unknown factors that shape re-building efforts; a tool that creates an environment of effective design for the betterment of communities and individuals in need.

Composed of live space, work space, and flexible communal space, Apparatus X provides a forum for community voice and the exchange of design thinking. The project is physically described in three ways: Adaptable tool trailer, Mobile Design Studio, and Micro-living unit.

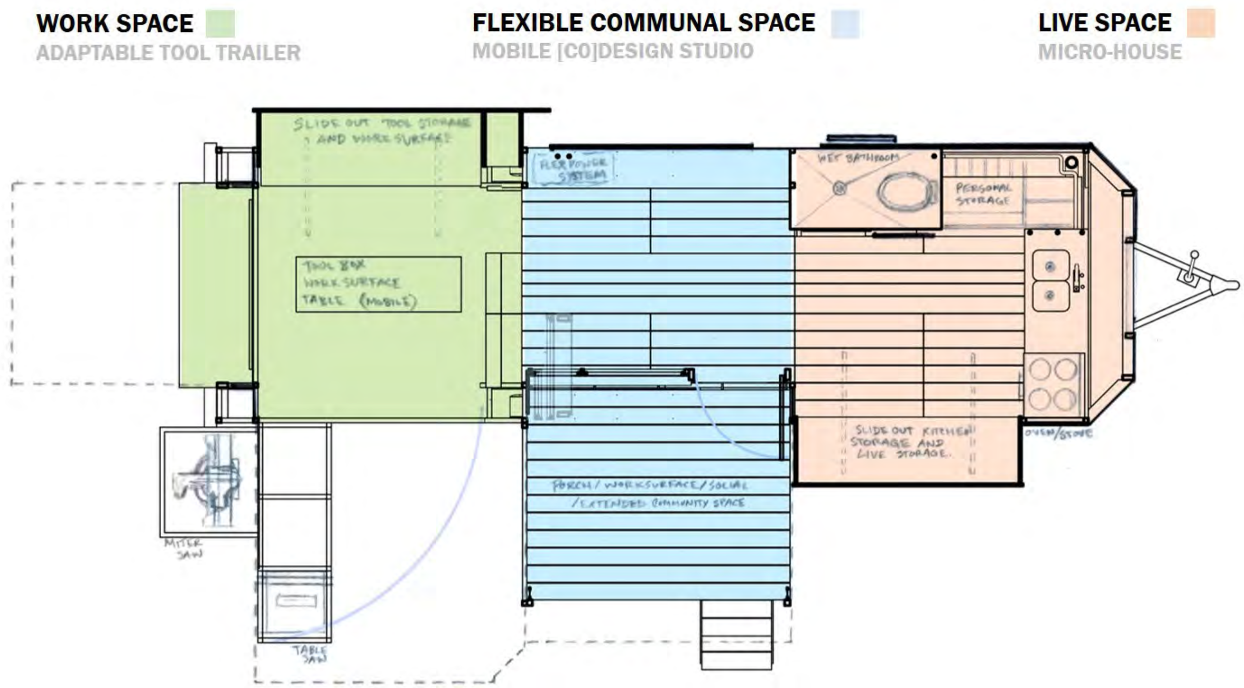
ADAPTABLE TOOL TRAILER

Tools harbor an embodied knowledge and memory. Tools are created as an extension of self to enable the completion of a task incapable of being competed by natural or human process/action alone. Since tools are typically governed by specificity of task – hammering, tightening a screw, nut, or bolt, sawing, prying cutting, etc. – dissociation of the tool with the task is nearly impossible. As a result, many tools prompt a natural interaction with the user, and thus inherently transmit knowledge and skill. Armed with a mastery of tools and the physical artifacts themselves, and activist architect can allow the tools to transmit knowledge with equal if not greater effectiveness than what the architect is able to articulate themselves.

Tools make an impossible task possible – provide strength. Tools are empowering – The tool alone cannot be productive, nor the hand alone be effective. The true strength lies in the marriage of the hand and the tool. Tools evolve. Apparatus X is the evolution of a tool. If a tool is created as an extension of self to enable the completion of a task incapable of being completed by natural or human process/action alone, then Apparatus X is the extension of a community enabling building projects and design that responds to the needs of the community that have not/are not being effectively addressed. As something that is not just reserved for the architect, Apparatus X is also the tool of the people, bringing the realm of architecture, including tools and design, to those who need it, and providing empowerment through building.

As an adaptable tool trailer, Apparatus X is capable of transforming an empty lot into a workspace. Building as empowerment is key to the intentions and success of Apparatus X. In order to build, a workspace, tools, and general means of construction are necessary. Since the variability of conditions of architectural activism sites will typically not be able to support a program of building/construction, it is required that Apparatus X is able to do so.

Through tooling, building, participatory design processes, or hands-on building and cleanup activities enabled by the interaction with Apparatus X, community members actively



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participate to make a difference in shaping their surrounding environment. As basic as this can be, participation acts as enabling activity renewing intangible aspects to community: pride, confidence, comfort, and care. In this sense, self-building holds two meanings: 1) the physical act of construction conducted by oneself, and 2) the intangible and internal fostering of confidence, pride, self-esteem, etc. within the character of an individual (similar to the activities that counseling service can offer).

MOBILE [CO]DESIGN STUDIO

With an open central module layout, Apparatus X acts as a mobile design studio for both individual and community design, and aims to foster collective knowledge and provide a collaborative learning environment. In order to make the profession accessible, the activist architect leaves the office and embeds in a place. To do so, an itinerant but functioning space must be able to provide similar capabilities and tools to the office counterpart.

As an additional aspect of Apparatus X aiming to enable greater participation and provide increased access to design tools, a projector is used in conjunction with a chalkboard surface to display information or drawings. Considering that drawing acts as a means of universal communication, large drawing surfaces are key to promoting design dialog, conveying ideas, and providing an inclusive medium. Through the use of alternative media strategies – photographs, chalkboards, and projections – design can build and develop across a multiplicity of perspective and inputs creating in a way a palimpsest of design intention.

MICRO-HOUSE

Apparatus X, the micro-home unit, functions efficiently and illustrates a comfortable and efficient living environment for the inhabitant – an activist architect. If travel and embedding into a community are essential, the unit must be able to provide support for living anywhere and everywhere.

Figure 4: *Expanded Spatial Layout of Apparatus X - Plan view,* (Drawing: aron Wertman)

The unit contains a small, enclosed wet bathroom including toilet and shower, a personal storage area for clothing and other items, a sink, stove, and oven operating on propane.

The bed is mounted on rails overhead (enabling even weight distribution and variable spatial arrangement), the underside of which doubles as a lighting fixture. The table folds out from the heavy rolling toolbox, and a porch extends from the passenger side. While it can be argued that a porch is unnecessary to the overall concept of the design, it is actually an important design feature addressing sensitivity to place as well as conveying that this is something more than just a mobile tool trailer. The porch, along with the kitchen table, is a place of informal thought exchange (friendly/neighborly conversation); A place of trust built through relationships; A place of home and comfort.

DESIGN/BUILD PROJECT EXECUTION OF APPARATUS X

In the physical sense, Apparatus X is a reconstructed recreation vehicle built and designed through collaboration using reclaimed and donated materials and a budget from contributors who believe in its cause, effectiveness, and importance. However, the physical product resulted from employing and practicing the ideals that help to define the activist architect. This project took on a second and perhaps more meaningful role in helping to develop the abilities and skill set of an activist architect because it developed in a multi-disciplinary academic setting. This network of engagement has a place in architectural education and can enhance the way in which more university programs foster the development of the activist architect, an area of needed expansion and acknowledgement.

The overall execution of the project resulted in a network of stakeholders and interest groups all of which negotiated and interacted with the project manager/student of architectural activism. Since a definitive hierarchy of the roles required to realize this project does not exist, it was necessary to nimbly respond to the situation at hand. The activist architect must be present and wear the hat that needs to be worn resulting in continuous cycling – designer, PR, administrative, political, finance, business, teacher, builder, networking, community member, student, friend.

The project prompted the facilitation of collaborations between student groups in architecture, engineering, and landscape architecture through an independent study course which provided experience in participatory design, collective knowledge, and reciprocal design and dialog. Materialistically, Apparatus X drew from diverse sources including salvaged materials from the theatre department, the university salvage yard, local builders, donated new products, and re-usable material from the deconstruction of the original RV unit, illustrating a necessary hyper-resourcefulness.

Ultimately, the action and facilitation required of the student project leader provided an experience in architectural activism and responsibility that poetically paralleled the roles and situations that are necessary and expected in the actual project implementation of Apparatus X in communities in need.

NEXT STEPS FOR X

The state of Apparatus X lies somewhere in the intersection (or perhaps the gap) of academy and practice (Fig. 5), and crosses the bounds of the profession in a way that is needed, but challenging. With a prepared physical presence, Apparatus X enables the activist architect to extend and engage communities in ways that are meaningful and sensitive, but comfortable through alternative acts of design thinking. Apparatus X takes advantage of the marginalized realm of activism, and supports the ability to contribute meaningfully to complex situations of the modern world regarding housing disparity, changing building paradigms, and limited resource availability. Apparatus X makes architecture accessible, engages in design activities and tasks WITH the community rather FOR the community, and creates a reciprocity/exchange/dialog of learning, design, and action. As an architectural variable, X will continue to evolve as a tool of architectural activism.

5

Figure 5: *An Interesting Intersection - or perhaps a Gap?,* (Diagram: Aaron Wertman)

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Rules of the Road: Connecting Cities to Underutilized Freeway Infrastructure Zones through Parametric Urbanism

Transportation infrastructure such as waterways, roads, railroads or the federal highways have always informed the design of cities. The National Interstate and Defense Highways Act of 1956 forever changed transportation, economic flows, connectivity and the landscape of the US. The mechanical efficiency required for the success of the freeway is created through separation from everything that might slow it down but benefits of speed created by separation are constantly at odds with slower, finer-grained, human concerns of dense urban cores. Rather than negate the rich existing conditions of rustbelt city infrastructure, Rules of the Road engages the parametric, Fordist logic of the freeway with the requirements a modern city and proposes parametric urban design strategies that mitigate environmental, social, and formal concerns with an architecture that engages large swaths of under-utilized freeway infrastructure zones.

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INTRODUCTION

The problem of designing transportation systems related to urbanism and architecture has existed since humans began migrating long distances. Roman roads allowed for movement across great distances for traders, pilgrims, and soldiers. These movements often created conflicts between those traveling and local villagers.[1] As transportation speeds increase and urban areas have become denser, the problems have become even more complicated. Where the transportation routes once defined and connected keys points of urbanism, today the speed and mobility of the automobile is viewed as a threat to good urbanism. As a design problem, the concern for transportation in close proximity to urbanism presents multiple dualities that are worth considering. From a visual and scenography perspective there is both the view of the infrastructure from the city and the ability to get elevated views of the city from this same infrastructure, both inside and outside of the infrastructure. Large scale regional transportation routes highlights the differences between being from a place and one who is passing through, local versus tourist, belonging and being an outsider. As we rely on faster machines for transportation, the speed differentiates the pedestrian from the passenger. Where so many dualities exist, simple binary solutions appear that either choose only one or provide solutions that are unable to address both halves of the duality.

The complications created by the proximity of transportation systems to other elements, urban or otherwise, have often seemed too complicated to address. As a result, a reductive mode of separation has been the prevailing design solution. During the Middle Ages the problem of clear sightlines was taken up by Edward I as a means to deter theft and murder of those engaged in regional transport. The Statute of Winchester in 1285 highlighted the expectation of clear and safe passage by creating a 200 foot right of way on each side of a regional road for clear sightlines. The statute stated that by decree 'there be neither dyke nor bush whereby a man may lurk to do harm'. It went onto to state that if a landowner did not clear the right of way and theft or murder occurred, then the landowner was responsible. There is already the biasing of the unobstructed movement in service of commerce and military needs over that of the adjacent local property. Additionally clear logistical and dimensional requirements are created and embedded in our understanding for the design of transportation systems.

The invention of the automobile and subsequent manufacture in the US had a profound impact on transportation, infrastructure, and urban settlement patterns. Prior to World War I there were 5 million cars and trucks registered in the US and in ten years following the quantity increased to five times that number.[2] The origins of the US interstate highway system begins with the Federal-Aid Highway Act of 1938 that chose a toll-free interregional network approach over a network of three north-south and three east-west toll superhighways to connect the whole United States. Building on this work, congress passed the Federal-Aid Highway Act of 1944. The act funded 50% of the construction costs and began 40,000 miles of roadway construction to connect cities, industrial centers, and key border crossings to support commerce and national defense. Because the initiative was a cost-share with state level funding, there was no comprehensive plan created. By the mid 1950's only 6,500 of the 40,000 miles of interstate highway had been completed. For national interest the National Interstate and Defense Highways Act of 1956 raised the federal cost share to 90% in order to complete the interstate highway system and became the largest public works program undertaken to that point in history.[3]

Because the highway was a latecomer to urban settlement, the planning for such projects adopted an approach of avoidance related to highway placement. The avoidance at a large scale was seen through the proposals like that of the townless highway by MacKaye and Mumford in "Townless Highways for the Motorist".[4] MacKaye the designer of the Appalachian Trail worked with Lawrence Halprin to reconcile the growing needs of technology while preserving the social, urban, and natural landscape conditions. Guidelines published by the American Association of State Highway Officials in 1957 in *A Policy on Arterial Highways in Urban Areas* offered suggestions of placement of urban freeways in order to minimize cost and disruption to the city. The suggestions included wedges of unused land, between ribbons of development, blighted areas slated for development, adjacent to rail lines or shores, or along the edge of already publicly owned parks or tracts of land.[5] What originates as avoidance tactics leaves us with a legacy of major infrastructure acting as urban walls or separation resulting from these decisions in Chicago along the lake and Boston along the river.

Throughout the development of the highway system there have been heated debates about where and how best to plan and locate the necessary infrastructure. Many disciplines fought for a stake from engineering to planning, landscape, and architecture. The politics surrounding these planning projects was intense. With the exception of a few early examples of multidisciplinary teams in the late 60's like that of the Baltimore's Inner

Harbor lead by SOM,[6] the "design' of highways has resided mainly in the domain of traffic engineers. What might the discipline of architecture be able to offer to the discussion now? Can architecture be redeployed to mediate the scale difference between infrastructure and city? Are there architectural maneuvers or methodologies that can be deployed to rethink aging infrastructure?

DESIGN THINKING

In *The Design of Business*, Roger Martin uses the metaphor of a "knowledge funnel"[7] to describe the development of an idea from mystery to heuristic to algorithm. As ideas move down the funnel they become easier to manage, execute and exploit. The ease of executing the algorithm is made possible because additional (and not always extraneous) information is shaved away. He proposes that businesses need to both exploit algorithms while simultaneously exploring new mysteries as part of a research and development campaign to develop new ideas, products and identify new markets as a means of staying competitive. Through a number of case studies Martin demonstrates the downfall of companies that focus solely on executing the algorithm because the market is constantly evolving. Mysteries might be difficult to develop but the potential for large benefits exists. As a cautionary tale, of the first Fortune 100 companies identified in 1955 only 11 still exist today, demonstrating the need for constant innovation in order to stay relevant and current.[8] Compare this low success rate over a long term to the lack of new knowledge being deployed related to the design of highways. It is easy to then apply this same metaphor toward the highway building program of the 1950's. It becomes clear that the development of an algorithm was deployed as a means to deliver the requested mileage in a short period of time, and much of the developmental practices ceased after this point. Using Martin's prompt to reinvest in the mystery, it is important to understand how much has changed and what potential might exist for new and innovative approaches and algorithms.

What Martin calls a mysterious problem, others might characterize as a wicked problem.[9] Given the nature of wicked problems in that they have no stopping rule, lack true or false solutions, and are unique, the ability for a design practice to take on such problems is incredibly limited given the financial burden of a service based industry. In contrast, the academic setting and academic practices are well-suited to take on these problems as a means of introducing students to the difficulties and realities of high-value design problems.[10] Ideally a collaboration could exist between professional practices with on the ground expertise and real commissions with an academic think-tank to provide a broader research and application perspective.

The urban highway was taken up as a design research topic and high-value problem because of its impact on large populations of people, its impact on multiple American cities, its rule based logic of geometric form, the need to address an increasingly aging infrastructure, and new technologies that threaten to undermine the prevailing rules for the highway system. As early as 1953, a period where Detroit was producing some of its largest cars, Lewis Mumford yearned for smaller electric cars with urban virtues of maneuverability and small parking footprints.[11] Electric and hybrid technologies are reducing or eliminating sound and pollution from cars. Autonomous technologies are addressing safety and traffic. Carpooling and ride sharing are taking on the financial burden of ownership and traffic. Projects like MIT Media Lab's "Reinventing the Automobile" addresses the design of the car and highlights the subsequent potential impact on the city from a broad stroke policy perspective.[12] Emissions, sound and safety were all very good reasons to provide greater distances from highways and buildings but as each of those topics are taken up by recent advances in automotive design it becomes an increasingly relevant exercise to rethink the long held beliefs about urbanism and transportation infrastructure from an architectural perspective.

Because it was the traffic engineer that became responsible for the design of transportation, many of the guidelines biased the quantitative, logistical, and algorithmic. Since the 1960's the early computer was used to make calculations and validate design strategies. In a 1973 report prepared by the OECD Research Group computational and optimization approaches highlighted potential benefits for design related issues of alignment in plan, alignment in section, and road link design. The design optimization impacted cost control and showed savings of 15% on related earthwork. The specific applications demonstrated in the report were all for rural road design because of "complication of the costs of land and structures in urban areas". To put this work in technological context, at the time results were transferred from one program to another through the use of cards, paper tape, and magnetic tape.[13] It is important to note that much of the future development work identified by the report addressed access to high quality data. The need for high quality data is becoming more available and recently more accessible through crowdsourcing, GIS applications and growing capabilities of recent big data initiatives.

Parametric modeling has advanced the ability to manage complex geometry and develop rule based models. Given obvious advances in computation, the logistics and algorithms native to the highway system were reconceptualized as a series of rules and parameters. Parametric modeling offers a means to manage the complexity of mass-customization while coordinating logistical constraints. Given the nature of rule-based designs that they do not necessarily lead to singular solutions, parametric modeling was chosen for its ability to simulate and represent multiple possible scenarios. Where non-parametric approaches must freeze design at one stage to progress to the next stage, the use of CATIA meant that early design decisions and parameters of rules could be tweaked even late in the design process. The intention is to develop this mode of working as a means of supporting a community planning process where the need to visualize possibilities exceeds the need for one final design proposal.

PRECEDENTS

There are a few early examples of architects using architecture to engage transportation and infrastructure. The car and movement were considered hallmarks of modernism and the language and form become inspiration for the precedents. Additionally architects understand urban context and it's value to see the way that various sites and urban conditions might inform both the architecture and the infrastructure.

As a traffic study project in Philadelphia in 1952, Louis Kahn devised a series of diagrams based on a governing principle that traffic should move based on hierarchical function. That is to say this new method of organization and movement throughout the city would be based on the functionality of different programmatic elements. What results is a condition in which the city dissolves away and only the conditions of movement begin to describe the functions of the city as a means to guard oneself from the ever present movement of the automobile.

In 1939 Norman Bel Geddes designed Futurama which proposed an infrastructural layout for the projected future of 1960's America. As Geddes was convinced of the notion that America would be fully integrated with automobiles by this point, Futurama becomes a means to advocate for a future living condition that embraces the density of the highway infrastructure. It also stands as a utopic vision that if actually realized would be a dystopic reality.

In 1910, Edgar Chambliss proposed a linear structure which integrates the extremities of residential and transportation conditions. Through a systematic layering of infrastructure, the residential corridor is placed up and away from the noises and barrages of traffic and roadways which cover a train station at the lower levels. While Roadtown stands as seemingly extreme example, these conditions fully advocate for the integration of the automobile into society, which speaks to a forward way of the thinking for the first half of the 20th century. Much like Roadtown, Sir Geoffrey Jellicoe's Motopia maps this style of layered infrastructure to the entirety of the city rather than separating the urbanism and infrastructure of 1959. In this instance, all automotive activity is raised to the roof whereas all pedestrian activity takes place at the ground. What results is an undisturbed landscape condition blanketed with architecture, holding automotive infrastructure above and out of view. While not directly dealing with the evolution of freeway infrastructure these design projects propose alternate views to infrastructure occupation and begin to help fuel the question of possibilities within architecture and highway infrastructural integration.

DESIGN RESEARCH–RULES OF THE ROAD

The highway is an important design element and construct of the 20th century. This element determines major urban distributions, migrations, and impacts. The urban highway is a major contributor to the design of cities. In most instances the transportation infrastructure is viewed negatively as a visual liability and is nearing the end of its lifetime. This presents a high value problem with impact in population and urban form. The problem is further complicated by difficulties in jurisdiction, land use, and emerging new technologies.

This research began with Chicago given its dependency on connectivity as a nexus of the United States. Rail lines and highways were a huge part of the mail order industry that began in Chicago. When the Dan Ryan Expressway was constructed in 1961 it was the busiest and widest highway in the world. The Research on the City Grant provided by Taubman College of Architecture and Urban Planning supported all research and design proposed for Chicago.

Detroit is the second city being studied as a rust belt urban center with a surplus of transportation infrastructure. Detroit offers an intriguing case study because of its strong automotive history. In comparison to Chicago where the urban transportation network is tightly constrained, Detroit has much more open space and more diversity of transportation morphology. The University of Michigan Office of Research Grant was awarded to extend research and design proposals for Detroit as a means of being able to compare and contrast as series of Rust Belt cities.

After acquainting ourselves with a comprehensive spectrum of historical precedent dealing in infrastructure, it became pertinent to choose sites within Chicago that exuded complexity in their pre-existing condition. Four complex interchanges were chosen for study: the northern exchange at I-94, the interchange at the South Loop at I-290 and I-94, the South Side interchange I-55 and 1-94, and the strip of infrastructure situated on I-94/I-90 between I-290 and I-55. Of the highway infrastructure situated across the city, these proved to be moments of potential for mediating infrastructure with architecture as defined by pre-existing spatial and traffic conditions. The northern exchange was unique in that it was a three way interchange which essentially fed and diverted traffic into and away from the freeway. The South Loop is hybridized roundabout condition that incorporates a tangled series of curves which became aptly known as the Spaghetti Bowl. The strip of freeway between I-290 and I-55 provides an interesting condition in that the series of continuous on and off ramps begin to create a new system of infrastructure with consistent moments of the structure visibly peeling away from itself. The South Side connection is a double interchange condition connected at a single point through a mutual southern highway at I-55 and adjacent to the river.

While performing preliminary analysis, it quickly became clear that gaining more knowledge about pre-existing freeway conditions would be beneficial before creating any new designs. This line of thinking led to the creation of an extensive taxonomy of pre-existing interchange condition diagrams, which simply demarcate the common formal trends of the system which will later influence the consciousness of design possibility.

What followed was a series of site analysis drawings and three dimensional models which give a much more precise visual of all formal site conditions. From here, the spatial qualities of the models were studied and manipulated in CATIA, the main modeling/design platform used in this project to quickly move the designs through a series of parameters which alter the form, occupation, and efficiency of all included spaces. Formal parameters were added to the preexisting spatial conditions and methodically transformed along a range of possibilities. Mapped out on a much larger scale, this practice occurred repetitively with varied formal constraints until resulting designs addressed multiple synthetic concerns as a means of overcoming reductivist and binary solutions. At this point in the study, the outputs were then assessed architecturally for their feasibility in construction as well as their possibility for increased and mixed programmatic activities. The designs that qualify for this portion of design development are then narrowed down, which subsequently receive a comprehensive design solution. This includes program, materials, systems, as well as further analysis of the effects that this new design will have on the pre-existing highway condition, which in some cases had been shifted out of its original position. The final product of this result is a sensitive architecture that fully accommodates all parametric constraints set and ultimately challenges the notion of usable space within the city condition.

O'HARE AIRPORT

A zone exists between the city of Chicago and the area defined by O'Hare International Airport. In this space it is a mix of city, state, and federal jurisdictions. Much like the highway that requires buffer zones as a means to mitigate speed differences between local and regional transportation, the airport also uses large setbacks to address the speed and sound of the runways. In this space multiple highways converge.

The Masters of Science Digital Technologies capstone studio explored the infrastructural zone adjacent to the airport. The approach was to investigate the highway space and explore possibilities for large scale planning related to deploying the highway as a means of defining space and urban patterns. By looking at flows and points of connection, horizontal geometry and patterns were explored. Rather than attempting to minimize the highway, an impossible task, we used the highway to create resulting urban structure. The broader pedagogical goal was to identify a topic, learn about its limits and rules, develop an understand that allows the material to become malleable, and then deploy that knowledge

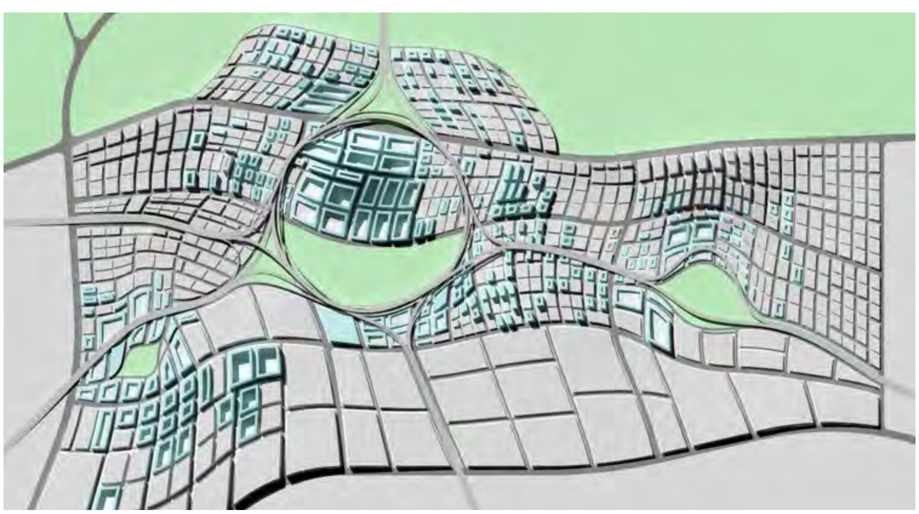

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Figure 1: Plan developed by MSDT capstone using super scaled roundabout. (See credits.)

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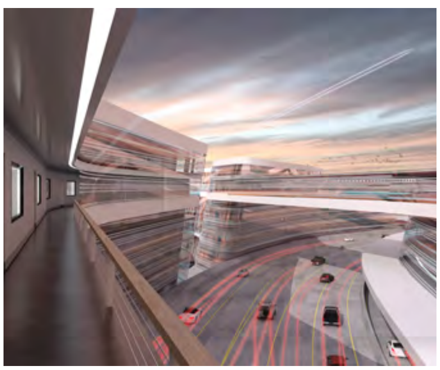
in a synthetic design application. While this work supported the Rules of the Road, the approach is imagined to be a transferable design/research approach.

CHICAGO LOOP

The Loop or Spaghetti Bowl in Chicago represents a massive urban block devoid of activity due to the highway. As a mode of avoidance, the highway was dropped into the void created by the Burnham Plan of 1909. What was originally reserved as a public civic plaza became a space for the automobile. As a means of testing the proximity of a human to a car, the proposals seeks to re-occupy the space in a large scale public manner without displacing the infrastructure. A large office building is proposed with an exterior public parking space which occupies a cloverleaf landscape proposal. Rather than hide the automobile from the pedestrian, the car is viewed as a sculptural trajectory that carves into the mass of the block.

SOUTHSIDE CHICAGO

In contrast to the Loop, the South side site was used as a means to engage a neighborhood residential fabric. Where the Loop represented a depressed condition the Southside site included an elevated freeway. This site focused on the continuity of the freeway and



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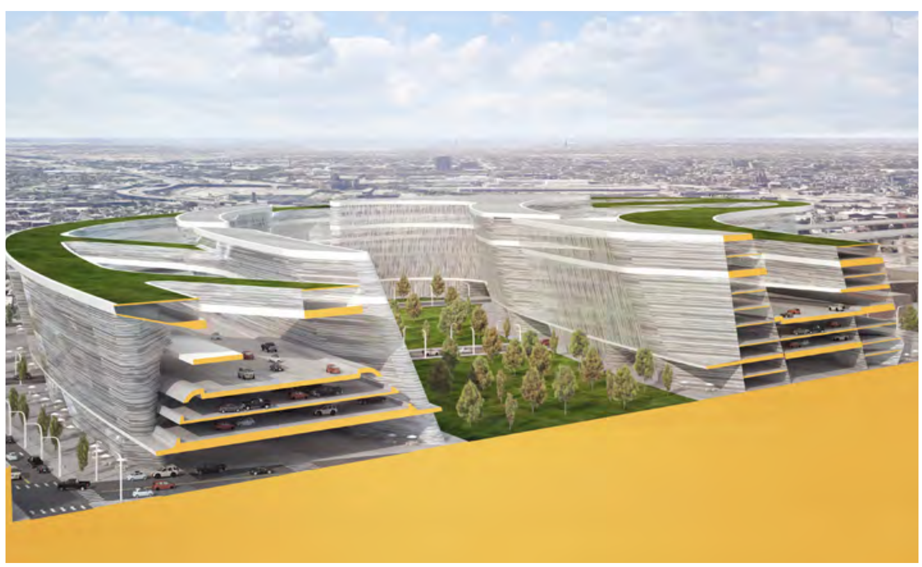

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Figure 2: Aerial view of South Loop site.
Figure 3: Section perspective of South Loop site.
Figure 4: Aerial view of South Side site.
Figure 5: Section perspective of South Side site. (See credits.)

examined the potential for cross-cut penetrations at the street level and visually for the passengers on the freeway. The cross cuts allow for local movement across the site making connections to and through an urban landscape. The cross-cuts break down the large form and provide driver and passenger glimpses of the local urban fabric below.

FUTURE DIRECTIONS

The work carried out as Rules of the Road is viewed as a series of phases. The O'Hare work was done as a design studio so that it would uncover issues, predilections, and preconceptions of highway infrastructure. The two case studies of Chicago were then carried out as a design research project as a large-scale architectural proposal. This work was carried out with a limited scope as a means to encourage the process of making and have a proposal to generate discussion and possibilities. The final work for the Chicago phase was presented as part of an exhibition. With this work as a starting point, the next stage includes an urban planner on the team for the work in Detroit. In the Detroit work, policy and market concerns such as privatization of infrastructure and the potential impact of those decisions will be a significant area of focus. There are discussions currently happening in Detroit about removing parts of the urban highways and the intention of this project is to get involved in some of those ongoing discussions.

PROJECT CREDITS

Masters of Science Digital Technologies Capstone Studio: Prof Karl Daubmann with Emad Khaled, Chris Byerly, Ana Faria Delfino, Punam Jensen, Han-Yuan Tsao, David Zhu.

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Rules of the Road - Detroit Design Team: Karl Daubmann with Brock Hinze, Mark Keller, Susan Landfried, Qetuwrah Reed, Stella Zhang.

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One Project at a Time: Service and Learning Applied in Appalachian Communties

"We saw hundreds of mountain peaks all around us, presenting a spectacle like ocean waves in a storm."[1]

D. JASON MILLER
Appalachian State University

R. CHADWICK EVERHART
Appalachian State University

BOOTSTRAPPING EDUCATION

Against a geographically isolated and economically – if not culturally – impoverished backdrop, brothers B.B. and D.D. Dougherty founded Watauga Academy, a forerunner of Appalachian State University, in 1899 to provide educational opportunity for the region. Its founding ethos reflected the character of its community: a self-reliant and self-sustaining institution with a pioneering and nimble spirit. From these humble beginnings, Appalachian State has emerged as a nationally-recognized regional university characterized by a commitment to sustainability and innovative education. It is an institution that appreciates a bootstrapping sensibility.

The Building Science program at Appalachian State University originated as a degree concentration in Construction Technology within the Industrial Arts and Technology program in the 1980s. Because Appalachian State University began as a college "to improve the education of teachers" in northwestern North Carolina; the Industrial Arts department, particularly the Construction Technology concentration, focused on training future high school and middle school drafting and wood shop teachers.[2]

As the university gradually transformed "from a single-purpose teachers college into a multipurpose regional university," so too did the Industrial Arts and Technology department.[3] By the late 1990s, the Construction Technology concentration developed a more professionally-based program of study, preparing students for careers in the construction industry in addition to vocational education settings. In 2006, the concentration became an official Bachelor of Science in Building Sciences degree program. Built upon a unique diversity of faculty expertise and encouraged by a high level of student interest, the applied-learning, sustainability-centric program organized two concentrations: one in Construction Management, the other in Architectural Technology and Design.

The Architectural Technology and Design concentration began in modest circumstances with only a few students occupying a small studio space – the proverbial one-room schoolhouse. Although the concentration was not developed as a NAAB program by intention rather than circumstance in order to preserve pedagogical adaptability, student numbers grew quickly because of the hands-on, interdisciplinary structure of the program curriculum. Within just a few years, the concentration expanded to accommodate approximately 100 majors, with students not only finding employment in architecture, construction, and engineering firms after graduation but also pursuing Master of Architecture degrees in programs across the southeast.

Today, the concentration in Architectural Technology and Design is an integral component of a comprehensive degree program that explores the building industry holistically. Now boasting three distinct yet convergent concentration tracks focusing on building design, building construction, and building performance, students in the Building Science program are exposed to an integrated and systemic approach to sustainability in the built environment. The program curriculum as a whole and the Architectural Technology and Design concentration in particular embrace systems thinking as a pedagogical variation of design thinking toward recognition and implementation of the interrelated flows of material, forces, and information in the design of buildings.[4]

This type of synthetic academic environment leans on the university's philosophical underpinnings to develop self-sustaining educational processes rooted to a sense of both place and craft as critical architectural values. As Richard Buchanan notes: "The significance of seeking a scientific basis for design does not lie in the likelihood of reducing design to one or another of the sciences … Rather, it lies in a concern to connect and integrate useful knowledge from the arts and sciences alike."[5] Thinking in this way involves not only the mechanics of design but raises specific inquiries about intention, about relevance, and about engagement.[6] It presents a set of hairy – yet enjoyably challenging – problems both academically and professionally whose epicenter may be found in asking (and re-asking) one vital and enduring question: how do you teach someone to function on their own *and* as part of a team?[7]

BOOTSTRAPPING PRACTICE

"Proceed and be bold."[8]

All too often, the commonly eviscerating critique goes, the primary disconnect between architectural education and architectural practice is akin to a supposed disconnect between the head and the hand, between thinking and making. The academy is not doing, the profession is not instructing, and so on. It is a tired yet persistent issue, one that cannot be dismissed easily or resolved singularly. A common sense approach of blending architectural education and architectural practice seems both obvious and necessary.

This is by no means a new idea, of course. It is instead a concept of abundant and rapidly increasing permutation, stretching from the rocky shoals of Nova Scotia (Ghost Lab) to the plains of Kansas (Studio 804) to the foothills of western Alabama (Rural Studio). These models have served to inform and inspire a professional trajectory toward jointly researched public interest architecture projects delivered from within the academic curriculum rather than working in parallel from without. The roots of this professional shift, however, stem from problem seeking within a rural cultural context that values above all else a problem solving capability to accomplish things competently and expediently with often limited means: in other words, bootstrapping.

At Appalachian State, what began with Industrial Arts faculty teaching a variety of subjects, including drafting and design courses, evolved into employing local architects as adjunct instructors teaching architectural design studios in the late-1990s. As the Building Science program grew in majors and student interest in the study of architecture increased, more permanent faculty positions were created. Chad Everhart and Jason Miller work as tenure-track faculty in the Building Science program and professional architects in the mountains of North Carolina. With each year, the connection between their professional and academic work deepens. In fact, it is increasingly difficult to delineate where each begins and ends relative to the other; however, this now delightfully blurry confluence was not always the case.

While the greater region of Appalachia is recognized as one of the poorest areas in the United States, many highly affluent pockets reside in the region around Boone and Watauga County, North Carolina – a microcosmic comingling of the so-called 99% and the wealthy. It is not uncommon to find multi-million dollar homes shoulder to shoulder with dilapidated single-wide trailers lacking basic utilities. Architectural services are viewed and consumed as a luxury product.

Because of these perceived limitations to activating professional relevance, both Everhart and Miller have positioned their practices in a manner that is responsive both to local inhabitants and the mountain context. Within their respective one-person firms, projects have been primarily small, sustainable, contextually-sensitive, and affordable, in direct contrast to the architectural self-indulgence inherent to the resorts dotting the mountainsides. Rather than scratching a living from a migratory population not unlike the Canada geese whose honking call seasonally fills the air, the authors elected to reposition the market of their architectural work.

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Shifting professional focus toward the academy afforded Everhart and Miller an opportunity to design like they give a damn, to paraphrase Cameron Sinclair, by pairing the unfiltered ideas of students with a receptive audience of community organizations well-stocked with need for design and construction services. With projects of modest requirements, modest means, and modest aspirations, Everhart and Miller have organized the architectural studio as an incubator of inspired design solutions because of, rather than in spite of, the constraints or limitations of a particular design problem.

ON EXPERIENTIAL SERVICE-LEARNING

"Pragmatism is the best teacher; learning is accelerated by purpose. We learn best when we need to know."[9]

While real-world application has intertwined frequently with the Building Science program through various projects and initiatives, the Architectural Technology and Design concentration's commitment to service-learning throughout its first nine years began with an impromptu phone call to the Blue Ridge Parkway, which resulted in students developing

Figure 1: Everhart (left) and Miller (second from left) with students at the Alleghany County Farmer's Market job site in Sparta, North Carolina.

proposals for a new visitor's center. The project validated service-learning within the context of architectural studios, established a studio culture within which to deploy similar projects, and facilitated a nascent educator/practitioner model for the architectural faculty.

Since this initial project with the Blue Ridge Parkway, numerous service-learning projects have occurred within the concentration's design studios. Projects completed to date range in scope from feasibility studies and master planning to integrated design and full-scale Design-Build. Clients or project partners have included a variety of non-profit organizations, government agencies, and other academic units or organizations at Appalachian State University. Students have worked variously as individuals and in collaborative groups, with certain projects lasting only a few weeks while others spanned multiple semesters. From 2007 to the present, the following service-learning projects have been executed in full or in part by Architectural Technology and Design students at Appalachian State:

This substantial list of service-learning projects demonstrates, in a relatively short period of time, a wide variety of building typologies, site conditions, and scopes of architectural

YEAR	PROJECT TYPE	CLIENT	SCOPE OF WORK
2007	Visitor Center	Blue Ridge Parkway	Design; Master Planning
	Bass Lake Comfort Stations	Blue Ridge Parkway	Design
2008	Comfort Facilities	Daniel Boone Native Gardens	Design
	Dining Hall and Housing	Holston Presbytery Camp	Design; Master Planning
	Community Housing	Watauga Habitat for Humanity	Design; Master Planning
2009	Duncan Hall Renovations	Appalachian State University Dept of Theater and Dance	Feasibility Study
	Community School	Two Rivers Community School	Design
	Conference Center	Holston Presbytery Camp	Design
	Mobile Performance Stage	Valle Crucis Community Park	Design-Build
2010	Learning Lodge	Grandfather Mountain	Design
2011	The Solar Homestead	US Department of Energy Solar Decathlon	Design-Build
2012	Teaching Barn	Appalachian State University Sustainable Development	Design-Build
	Central Park and Pavilion	Spruce Pine Main Street	Design; Master Planning
2014	Maison Reciprocity	CSTB Solar (France) Solar Decathlon Europe	Design-Build; Urban Planning
	Composting Privies	Appalachian State University Sustainable Development	Design-Build
2015	Farmer's Market	Alleghany County and Town of Sparta	Design-Build
	Welcome Center	Valle Crucis Community Park	Design-Build
	Farmhouse Adaptive Reuse	The Summit at Lost Ridge	Design; Master Planning
	Tiny Home Community	Appalachian State University Center for Entrepreneurship	Feasibility Study; Design

2

service; however, more informative to a study of academic and professional intersections are the project delivery methods employed. The following case studies compare projects sharing similar scopes, similar clients, and/or similar geographic locations while highlighting their differing objectives and execution strategies. In addition, each project reveals a sequence of architectural ethics instilled, rather than dictated, by Everhart and Miller's professional experience working in and for a rural Appalachian community: to value the importance of context (and its many unique layers); to understand the logic of local construction; and to implement the possibilities of sustainable technology and prefabrication.

Single Semester vs Multiple Semester

Most design projects within the Building Science program over the previous eight years have been developed as single semester activities. Within individual semesters, many service-learning projects have accounted for fifty percent or less of the total coursework in the studio. Since these projects are executed quickly, their design intention and community effectiveness is often conceptual; however, several single semester projects have been investigated more thoroughly and detailed in a manner similar to the program's limited portfolio of multi-semester endeavors. The first case study compares a single semester Design-Build project with a multi-semester Design-Build project for the same client: Valle Crucis Community Park in Valle Crucis, North Carolina.

In Valle Crucis, a small, historical crossroads within a rural landscape, the Building Science program has engaged in two significant projects for the same client: Valle Crucis Community Park. The privately-funded, non-profit park has a very small operating budget but large facility needs due to its popularity with local and non-local community members.

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The first project, a mobile performance stage, was a single semester effort in the fall semester of 2009. Fifteen students from the senior-level architectural studio began the semester by analyzing the larger context of Valle Crucis – a National Historic Rural area – as well the park itself. Upon completion of the analysis, several critical constraints were identified, including a 100-year floodway designation, which informed locations, floor heights, and construction techniques. As a result, the final scheme was really a collection of vehicles – rather than buildings – that combined to create a performance stage and pavilion. To circumvent the floodway issue, the stage was assembled upon robust flat-bed utility trailers that could be moved easily in case of flooding. This design strategy also proved valuable as a means to bypass the planning and inspections process, which would have

Figure 2: Views of Design-Build projects for Valle Crucis Community Park: *Mobile Performance Stage* (2009) and *Welcome Center* (2015)

inevitably slowed or halted a single-semester Design-Build project. In addition, the three-trailer mobile design strategy provided the ability to prefabricate components and fully assemble a final product on-campus with one-day delivery and set up on site.

Following the success of the mobile performance stage, the park engaged the Building Science program again in 2014 to aid with more a substantial project: a small visitor's center. With desperate need for additional restrooms, an office for the executive director, and indoor meeting space, it became clear that this permanent structure would be a multi-semester project. Building upon previous contextual analysis, research into the site and programmatic constraints – including the recurring floodway issue and historic preservation standards – informed the building's site position, foundation system, and exterior appearance. These constraints were intended to be addressed fully during the fall semester of 2014, which served as the "design" semester; however, bureaucratic complexities and inadequate time management by the student team prolonged the design process until midway through the spring semester, thus delaying the beginning of construction. Ultimately, the intricacy of the project and a (non)collaborative dynamic of the eight-person student team resulted in delays that impacted the completion date. A two-semester project transformed in to a three-semester project.

DESIGN-ONLY VS DESIGN-BUILD

The Building Science program has benefited from both design-only and Design-Build sponsored studio projects. One of the greatest factors in determining the architectural scope of services provided for a client is the amount of funding available to the project. While funding is tied, by default, to construction activities, challenging design problems require financial commitment from those requesting work from the studio. The second case study evaluates a funded design-only studio against a funded Design-Build studio which occurred simultaneously with the same cohort of students.

In the spring semester of 2012, Everhart and Miller embarked on two distinct service-learning journeys with two different sections of the senior architectural design studio. One section, led by Professor Miller, engaged a community group from nearby Spruce Pine in Mitchell County, North Carolina for a design-only experience, while the other section, led by Professor Everhart, participated in a Design-Build experience with another academic unit at Appalachian State. Both projects might be best classified as "out-of-town" work, with Miller's studio designing for a downtown infill site one hour south of campus and Everhart's studio working on a rural and historic farm property thirty minutes east of Boone.

Miller guided a collaborative team of ten Building Science students and twenty Interior Design students through the complete range of architectural services on behalf of the sponsored studio's client, Spruce Pine Main Street, a non-profit organization in Spruce Pine, North Carolina. The programmatic need was simple enough: provide design proposals for a small pocket park and office space on an infill site fronting one of the two main streets in the community's downtown district. Not so simple was the community need for the project to mend the physical and emotional scars left by a devastating act of arson in 2007. The studio first "unpacked" the Town of Spruce Pine through analysis, research, and interviews in order to understand its anatomy and establish a "we-based" communication strategy with community members.[10] This contextual research shaped a predesign phase of program development, site documentation, and precedent analysis which, in turn, informed the design phases for the ten project teams (composed of one Building Science student and two Interior Design students). These ten teams presented their final design proposals to gauge community interest and response. Based upon community feedback, a small team of students prepared and documented a final design scheme approved by the Spruce Pine Main Street board for implementation when fundraising efforts concluded. For a meager

$2,500, the studio provided the client and the Town of Spruce Pine with: [1] a four-hundred page analytical document including proposed design and development guidelines; [2] a three foot x seven foot presentation site model; [3] promotional, branding, and fundraising materials for Spruce Pine Main Street; and [4] a student-designed, student-built project information kiosk installed on the downtown site.

3

A smaller group of eight Building Science students were shepherded by Everhart to design and build a Teaching Barn for the Sustainable Development Teaching and Research Farm in Ashe County, North Carolina. With a very small construction budget of $10,000 and a single-semester timeline, each of the eight students analyzed the farm as a context and developed individual schematic designs for the building at the beginning of the semester, which informed a final collaborative scheme. After synthesizing client comments from the individual projects as well as revisiting the budget, site constraints, and programmatic needs, the students collaboratively designed an “off-the-shelf” structure of built-up dimensional lumber clad in planking harvested and milled on site. Because the project was located on an actual working farm, roads and other infrastructure were very limited. To address these issues as well as a quick four-week build schedule, the structure was prefabricated into panels and components in the program’s high-bay construction lab. After dry-fitting the structure on campus, it was disassembled and reassembled on a minimalist concrete pier foundation system in a meadow adjacent to the farm’s principal access road and gardening areas.

Figure 3: Views of *Main Street Central Park and Pavilion* in Spruce Pine, NC (2012) and *Teaching Barn* in Ashe County, NC (2012)

PROBLEM-SOLVING VS PROBLEM-SEEKING

The Building Science program has worked primarily with community groups with predetermined project scopes, which is often how service-learning is identified or categorized; however, some of the program's pursuits have been more speculative than reactive in addressing community needs. The third case study investigates a community-initiated, problem solving project and a problem seeking, community-partnership design proposal. Both projects were Design-Build ventures, although one was heavily grounded in its local context while the other suggested a mass customizable prototype solution.

4

In the spring of 2014, the Town of Sparta and Alleghany County contacted the Building Science program regarding their need to construct a permanent farmer's market facility. Operating with pop-up tents in a gravel parking area, the new farmer's market structure was considered by the two collaborating government entities to be an economic catalyst and visible landmark in the small, rural, and historically impoverished community. After thorough context analysis and precedent research, the eight-student team developed collaboratively three conceptual schemes in the fall of 2014, which they presented to the Town Council and County Commissioners for feedback. Working directly with the County Manager and Town Manager as their primary clients, the students integrated feedback into a final design, which was again presented for review by the two governing bodies. After receiving approvals from the community, the design was used to acquire additional grant funds and detailed for construction through late winter of 2015 when prefabricated construction began. The project included significant community collaboration not only

Figure 4: Views of A*lleghany County Farmer's Market* in Sparta, NC (2015) and Mixed-Use *Quartier Reciprocity* in Winston-Salem, NC (2014)

during the design phase, but during construction as well with county and town employees assisting with excavation, grading, and pre-fabricated component erection.

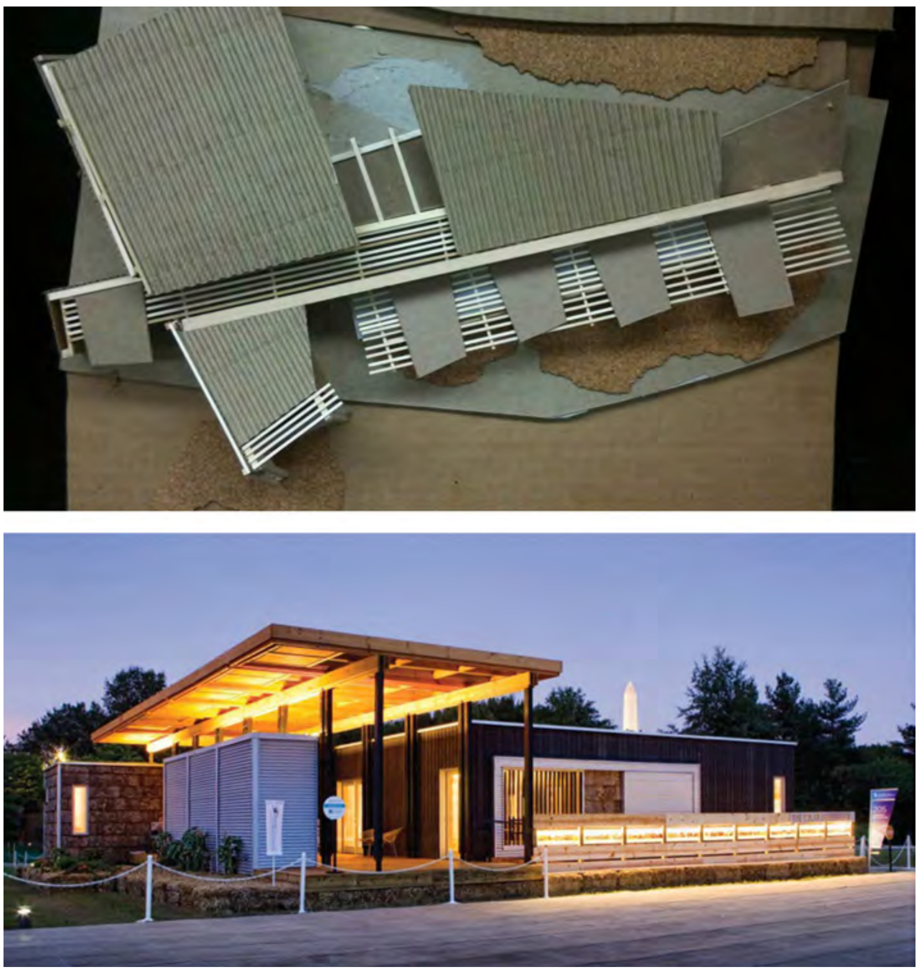
From 2012 to 2014, students from the Building Science program participated as part of an interdisciplinary, transatlantic team in the Solar Decathlon Europe 2014 with its entry Maison Reciprocity. Unique to the Solar Decathlon Europe is a dual responsibility to solve problems and seek problems: to design, build, and commission a high-performance building prototype for the international competition; and to develop a comprehensive design proposal addressing housing needs in an urban environment. The requirement to look at urban housing issues led the integrated design team of undergraduate and graduate students to ask an important if somewhat obvious question, "What does it mean to live well?" In Winston-Salem, North Carolina, a mid-sized city at the foot of the Blue Ridge Mountains, the team identified a community in transition from its founding tobacco industry roots to biotech and medical research with a specific need for affordable mixed-use housing in the heart of downtown. After developing research partnerships with two local agencies, the Goler Community Development Corporation and the Housing Authority of Winston-Salem, the team developed a market-centric urban design proposal. Quartier Reciprocity explored a model for fine-grained urban development and economic generation by restoring the centrality of mixed-use, mixed-income neighborhoods within the urban fabric. The plan offered a framework, or systems-based approach, for neighborhood design to create a socially and economically diverse mix of housing units, commercial spaces, and communal outdoor areas. The team's proactive, pro-city business and master plan was well-received by its partner agencies and the Winston-Salem community, leading to ongoing discussions on implementation of the proposal into HAWS strategic planning initiatives and licensing the Maison Reciprocity row house design for speculative social housing development and mass production.

SINGLE DISCIPLINE VS INTERDISCIPLINARY

While the initial service learning projects executed by the program were only with students in the Architectural Technology and Design concentration, many projects have since incorporated students from other disciplines. The interdisciplinary approach has proved incredibly effective not only with complex programmatic or site issues, but also when dealing with issues of sustainability. The fourth case study compares two projects – one single discipline and the other interdisciplinary – whose primary objective was to be net zero in regards to energy consumption.

In the spring semester of 2010, fifteen students worked with the Grandfather Mountain Stewardship Foundation to develop individual design options for a potential project called "The Learning Lodge." In an effort to consolidate disparate research endeavors on Grandfather Mountain by various academic and non-profit organizations, the Foundation desired a facility to house researchers under one roof. Besides acknowledging the inherent view shed issues and rugged landscape, the client mandated one major thesis: a self-sufficient, sustainably constructed, net-zero energy facility. While the Architectural Technology and Design students spent considerable time researching and developing sustainable strategies for their individual design proposals, the final schemes ultimately were more architecturally focused. The Foundation was able to use the semester's work as a pre-design exercise, which assisted the crafting of a competitive Request for Proposals (RFP) document.

From 2009 to 2011, students from the Building Science program participated as part of an interdisciplinary team in the US Department of Energy's 2011 Solar Decathlon in Washington, DC, with its entry The Solar Homestead. The 2011 competition, like each occurrence of the biennial event, asks student-led teams to design, build, and commission a net-zero energy building prototype; however, unique to the 2011 competition was the inclusion of affordable housing and cost estimation. Rather than beginning the conceptual design phase with only Architectural Technology and Design students, the faculty assembled an interdisciplinary, multi-generational group of eight students as the core design team. The students included two Architectural Technology and Design undergraduates, three Interior Design undergraduates, and three Appropriate Technology graduate students with undergraduate backgrounds in construction management, architecture, and communications, respectively. As the conceptual design evolved to a more concrete design solution, the interdisciplinary team grew as well. By the end of the two year event, over one hundred students from disciplines across campus participated and a core Design-Build-test team of thirty made the trip to the National Mall in the fall of 2011. The Solar Homestead, winner of the coveted People's Choice Award and a finalist in four of the ten juried and measured contests, was an embodiment of seamless renewable energy integration into a buildable, architecturally expressive project. This project not only transformed the program's approach to student team composition, but fostered interdisciplinary faculty research and pedagogical approaches via applied design and construction projects.



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BOOTSTRAPPING EDUCATION WITH PRACTICE

A term usually deployed in reference to a self-sustaining process or an unorthodox yet effective action, the interpretation of bootstrapping as an architectural approach for the educator/practitioner reflects both the cultural context of the southern Appalachian region and of a Building Science program that traces its origins to an academic department focused

Figure 5: Views of *Grandfather Mountain Learning Lodge* (2010) and *The Solar Homestead* (2011)

on manual training (c. 1918). While this approach does not suggest nor have interest in a universal solution to conjoin the academy with professional practice, it does present an interesting point of intersection for these parallel architectural trajectories and offers some useful observations about how professional "real-ness" might intertwine effectively with a service-learning pedagogical model.

The case study projects completed through the Building Science program and its Architectural Technology and Design concentration have been professionally instructive precisely because they eschew dogmatic philosophies and narrow scope of work definitions. Both design-only and Design-Build studio projects bring value to the community; the legacies of each are simply measured on different temporal scales. Projects executed across multiple semesters prove to be more critically and constructively engaging for students, faculty, and community members. Team dynamics and communication are consistently the most challenging issues in the studio environment; interdisciplinary groups often engender a stronger team culture and better calibrated project solutions economically, systemically, and architecturally.

The academic and professional synthesis embedded in these service-learning projects reaffirms the idea that problem seeking and problem solving cannot stand on their own, that the essential service of architecture is to provide both for its community.

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From Disaster to Resilience

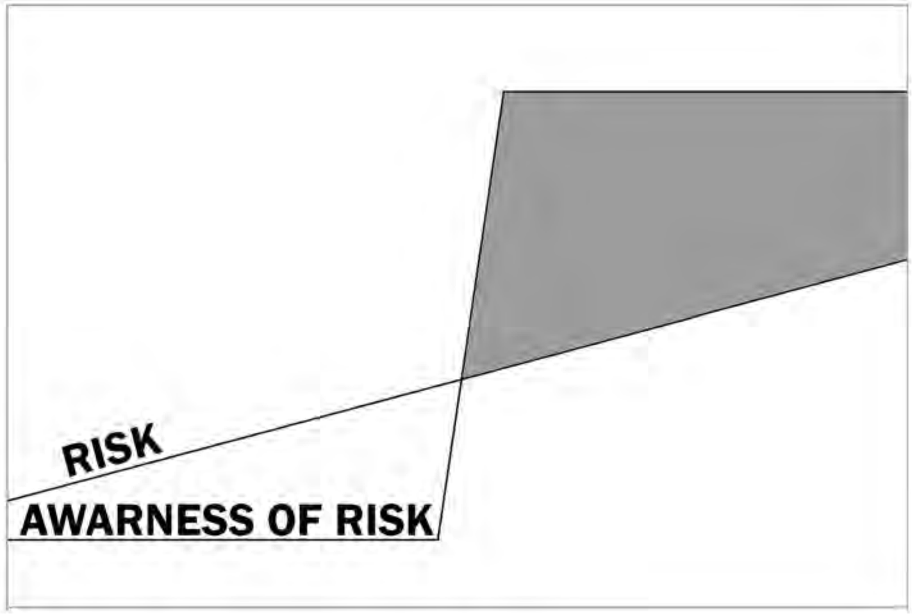
What is changing in the world so that the word “resilience” is so frequently used? 2015 marks the ten year anniversary of Hurricane Katrina and the five year anniversary of the Gulf of Mexico oil spill. The Gulf Coast Community Design Studio has been working on the Mississippi Gulf Coast since Hurricane Katrina and their work provides the vantage point of this paper. The Gulf Coast Community Design Studio is an off-campus research and service center of Mississippi State University College of Architecture, Art and Design located in Biloxi, Mississippi. It was created to respond to Hurricane Katrina and has evolved from disaster response to long-term efforts of resilience. The design studio’s evolution is not an isolated story. It is part of a national move toward resilience.

DAVID PERKES
Mississippi State University

The diagram below depicts the relationship of risk and awareness of risk. Risk is steadily increasing because natural hazards are increasing and because our increasingly urbanized, industrialized, global economy is dependent upon systems that are vulnerable to failure. However, even though risk is increasing at a steady rate, the awareness of risk changes abruptly with events such as Hurricane Katrina, the Gulf of Mexico oil spill, Super Storm Sandy, etc. Such disruptive events change the public’s attention to risk and stimulate cooperative work. The shaded zone is the working space of resilience and can be thought of as the work to cooperate risk.

As disruptive events happen more frequently and effect more people the public’s awareness of risk remains heightened and becomes a concern that doesn’t go away. Such is the condition of the twenty-first century, a condition in which there is a nagging awareness of increasing risk. Such awareness has an emotional dimension, especially when we consider that natural hazards are uncertain and images of disaster in some other part of the world remind us that the particular place we call home could be hit next. In the context of risk, the word “resilience” is used to counteract uncertainty. It stands against uncertainty and even though we do not know precisely what we are going to do to become resilient we agree that we should be doing something.

In the ten years since Hurricane Katrina the work of MSU’s Gulf Coast Community Design Studio has paralleled a national move toward resilience. Their work has been part of a series of national programs and sources of funding that mark a path from disaster recovery to resilience. The design studio’s work and the parallel national path toward resilience include:



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- 2006-2009 - HUD Rebuilding America Partnership Grant.
- 2008-2012 - HUD Community Development Block Grant Disaster Recovery funding to produce Long Term Work Force Housing to replace houses lost in Katrina.
- 2009-2012 - Department of Homeland Security South East Region Research Initiative (SERRI) funding to research Flood-proof Construction and Temporary Disaster Housing.
- 2010-2015 – National Fish and Wildlife Foundation funding for inner city tidal marsh restoration following the BP Gulf of Mexico Oil Spill.
- 2010-2013 – HUD Sustainable Communities Initiative.
- 2013-2014 - HUD Rebuild By Design
- 2014-2015 - HUD National Disaster Resilience Competition

Four resilience lessons from the work of the Gulf Coast Community Design Studio stand out: realism, collaboration, information, and design.

REALISM

The word “resilience” was not a noticeable part of the work on the Gulf Coast In the first few years following Hurricane Katrina. Other words were common such as “rebuilding, recovery, renewal, Renaissance,” all words that pointed to a return to at least a prior condition and hopefully to a better version of the past. From a ten year vantage point the official language used soon after Katrina shows a remarkable idealism and an effort to simplify the traumatic loss and confusion.

Within weeks of the disaster, under the effective leadership of Governor Haley Barbour, Andres Duany with the help of architects and planners from around the country associated with the Congress for the New Urbanism were enlisted for an unprecedented planning effort officially called “ The Governor’s Renewal Forum” but commonly referred to as the “Governor’s Charrette.” It is safe to say there has never been such a gathering of planning professionals brought in and put to work in such a place in such short order. Over 100

Figure 1: Risk vs Awareness of Risk

architects, planners, engineers and other professionals from outside the state were joined by nearly the same number of local professionals. The charrette took place in the middle of October, just six weeks after the storm. The work space was in one of the shuttered casino hotels already busy with contractors working to get the casino back on line. Outside the improvised workspace, the damage on the coast was stunning and destroyed areas were still under military guard. The contrast between lovingly rendered drawings being pinned up inside the hotel, and the view just outside the hotel of a massive four-story casino barge smashed into the side of the hotel's parking garage was almost impossible to reconcile.

Words from the opening pages of the Governor's Commission Report characterize the idealism of the planning effort:

"Throughout the Renewal Forum and the work of the Commission, South Mississippi has been referred to as a "clean slate," providing an enormous opportunity to rebuild in a way that optimizes the natural beauty of the Gulf Coast. Nowhere is this statement more accurate than with regard to the Highway 90 corridor. Hurricane Katrina's winds and flood waters destroyed most, if not all, of the existing structures along this corridor. From Waveland to Pascagoula, the structural remains can be described as a fresh canvas awaiting a skilled artist's creativity."[1]

Nearly ten years later, it is difficult to not cringe at words such as "clean slate" and "fresh canvas" considering the reality of the Mississippi Gulf Coast. Even though the lots cleared of houses by the storm surge appeared to be open land ready for development, the thousands of property owners that lost their houses still owned the property. Furthermore, this far-from-clean slate became much messier as the FEMA flood insurance rate maps were drastically revised, flood and wind insurance shot up to exceed the cost of many homeowners' mortgages, policy changed to allow casinos built on land, and accordingly, anticipating a booming tourism and casino market, cities along the coast re-zoned residential property into water-front development, resulting in a highly speculative real estate market. Thus, the fresh canvas that only lacked the artist's touch in the idealism of renewal was in reality a very confusing and difficult place to build. Even though the open land looked simple, the underlying conditions of uncertainly had dramatically increased. Uncertainty increased further with the 2008 recession, which for the most part took away the casino and condominium market, followed by the 2010 oil spill, which for a time took away much of the tourism and commercial fishing market.

Soon after the storm the Gulf Coast Community Design Studio started working in East Biloxi, setting up an improvised workspace on the second floor of a church building that had been temporarily transformed into a coordination center. East Biloxi is an historic, low-income community in an area four miles long and one mile across at the tip of the Biloxi peninsula. Most of the peninsula is less then twelve feet above sea level, and it borders on the Gulf of Mexico to the south and the Back Bay to the north. Hurricane Katrina's unprecedented storm surge, which was well over twenty feet in Biloxi, inundated the entire peninsula, affecting every house. When the water subsided, nearly half of the existing four thousand houses had been completely destroyed and the other half had been flooded.

The design studio's first community assistance illustrates the lesson of realism. East Biloxi was a confusing place to work with overwhelming needs of a traumatized community and hundreds of volunteers who came to help. To help communicate and coordinate the relief and clean-up efforts the design studio produced what became known at the "grid map," dividing East Biloxi into 24 numbered blocks. Stacks of the color grid maps, reproduced on 11" x 17" paper, were used by dozens of organizations to plan and distribute relief and rebuilding activities. The relatively simple task of making a useful map had a magnified impact. The primary function was coordinating relief activities, but there were two byproducts of the grid map. First, the community looked at the map and was able to envision an organized relief effort at a time when everyone felt overwhelmed and confused, focusing the community's attention on the East Biloxi Coordination and Relief Center as the place where help could be found. The second byproduct was the way the grid map introduced the community and relief organizations to the Gulf Coast Community Design Studio. Many people in the community were already suspicious of outside planners because of the Governor's Charrette. Despite the charrette's positive publicity and support from state leaders, many residents were upset that they had been left out of the process and were offended that a planning firm from California was producing idealized images of "what East Biloxi could look like." The fact that the Gulf Coast Community Design Studio simply made clear and useful maps that provided realistic information was important to gain the community's trust. Following the aim of realism the design studio produced many maps, including flood maps to explain the confusing FEMA advisory flood levels, maps showing the disproportionate impact of the hurricane damage on Biloxi's Vietnamese community, maps showing the change of policy for casinos now allowed to be built within 800 feet of the coast line, and others. The community soon came to know that the Gulf Coast Community Design Studio has the expertise and engagement with the community to produce useful maps.

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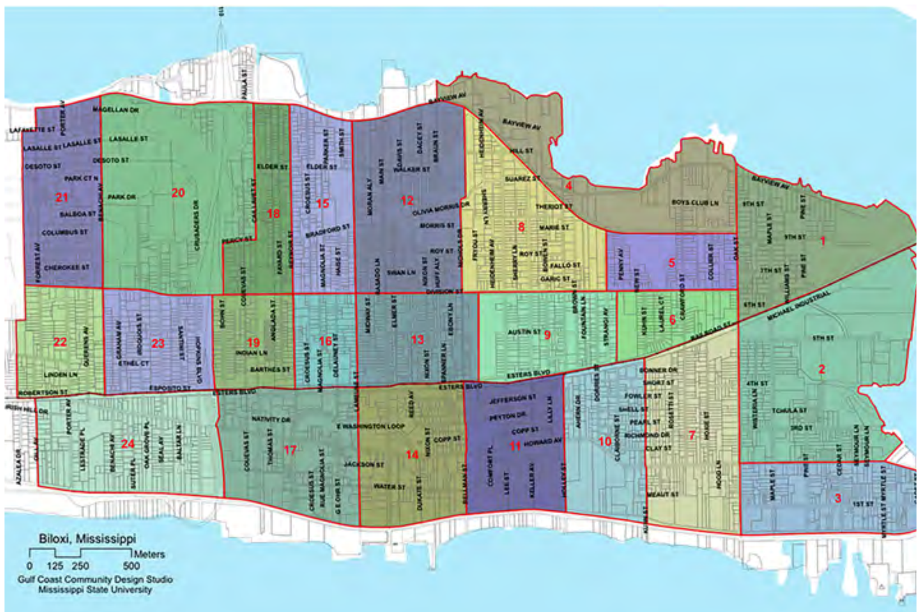

Figure 2: East Biloxi Grid Map - GCCDS

The mapping work led to several neighborhood planning projects in which the design studio took an asset-based approach, showing the community what they have to work with and helping them make realistic decisions. In practice, resilience planning asks the questions: What are the community's existing strengths and vulnerabilities? What risks are anticipated in the future? What can be done to address the vulnerabilities and prepare for future risks? Such questions require a community to be willing to be realistic and require planners to be willing to listen and not find themselves producing images of the future that might look appealing but are too far from reality to be useful.

COLLABORATION

The overwhelming needs of a disaster and the equally confusing resource of volunteers and assistance programs lead to an unusual degree of collaboration. From its beginning the Gulf Coast Community Design Studio has collaborated with dozens of community partners. The obvious need to collaborate in response to Hurricane Katrina led to long-term cooperative relationships that have effectively evolved into the work of resilience. Resilience at the scale of a city can only be imagined with the same high level of collaboration that is required for disaster recovery. This collaboration is vertical and horizontal: vertical, in that the interrelated parts in the line of action from localized need up to the federal agency or foundation aiming to address the needs are coordinated; and horizontal, in that parallel activities that might normally compete and neighboring organizations that might normally define their work narrowly learn to cross boundaries and work with each other.

The Gulf Coast Community Design Studio has proven the effectiveness of both vertical and horizontal collaboration. The staff consists of architects, planners and landscape architects working on a broad range of projects in collaboration with many community partners. The design studio operates with grants and contracts as an off-campus research center through the university's Office of Sponsored Programs. However, their work environment looks more like a design firm than a research center; and their projects have as much outreach and design work as research. Every project has community partners, multiple partners in most cases, and all the work is shaped by a commitment to engage the public. This commitment stems from both social justice values and from a pragmatic approach to achieve better results.

The lessons of collaboration and its role in resilience are demonstrated in two design studio projects: Katrina replacement houses and Bayou Auguste restoration.

Hurricane Katrina resulted in overwhelming housing needs in cities along the Gulf Coast. The Gulf Coast Community Design Studio's response was shaped by three realizations. First, design services alone would not be effective and needed to be part of a comprehensive case management approach. Second, to ensure long-term impact, families that are going to live in the houses should be included in the design process so that the resulting houses are a good fit. Third, the construction labor force after a large disaster consists of inexperienced volunteers, changing site supervisors, builders who might not understand hurricane zone construction and other unusual situations so the architect's role during construction is different than for a typical contractor project.

For eight years, with various funding sources, the Gulf Coast Community Design Studio provided architectural services for over 230 new houses and over 100 rehabilitated houses. Each house was designed specifically for the family and site. The design studio worked with seven primary partner organizations: The East Biloxi Coordination and Relief Center, which was renamed Hope Community Development Agency; International Relief and Development (IRD), which evolved into Climb Community Development Corporation; The Biloxi Housing Authority; Hancock Housing Resources Center; Back Bay Mission; Habitat for Humanity Gulf Coast, and Habitat for Humanity Bay-Waveland. Each partner organization did the work on either side of the design studio work: case management leading up to design, and construction management to get the houses built. In all cases the design studio provided architectural services for low-income households that qualified for various assistance programs.

The project organization and contract arrangements were designed to support effective collaboration. Vertical collaboration was facilitated in the way the design studio was paid. Under three different agreements utilizing HUD funds the Gulf Coast Community Design Studio was directly paid to provide architectural services to multiple non-profit building organizations. The homeowners, all of whom were getting assistance, were not required to pay for design services. What's more, the seven partners mentioned above did not need to include design services in their budgets, because those cost were covered from HUD through the state to the design studio. This allowed the design studio to manage their own work and create a method that efficiently repeated construction details but was able to develop individualized floor plans, site plans, kitchen layouts, porches, etc., with extensive

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homeowner involvement. This design-driven approach created houses that have been well received by the community and are likely to be houses that families will commit to and pass on to their children, thus helping to restore and sustain neighborhoods that were impacted by Hurricane Katrina. The sample of completed houses below illustrates the range of designs, evidence that the homeowners' decisions significantly shaped the designs.

Horizontal collaboration between the design studio and their partners was made possible by long-term cooperative relationships, reinforced by the fact that the partners did not pay for design services so that the design studio's commitment to the project was never reduced to a debate about fees. The horizontal collaboration was especially apparent in that the Gulf Coast Community Design Studio put their workspace in the same building as the East Biloxi Coordination and Relief Center to allow ongoing, day-to-day communication with the case managers, construction coordinators, and the hundreds of East Biloxi residents that came into the center. The homeowners going through the assistance process experienced the design studio as part of what the community called "The Coordination Center," not as a separate university program.

The Bayou Auguste restoration project collaborated with multiple community partners to transform a degraded tidal stream into a resilient landscape, creating a public asset for a historically underserved community. The project is part of a community plan for East Biloxi, a low-income, racially-mixed community devastated by Hurricane Katrina. The Gulf Coast Community Design Studio secured multiple grants, leading a partnership including the City

Figure 3: Katrina Replacement Houses

of Biloxi, Biloxi Housing Authority, Biloxi Public School District, and the Land Trust for the Mississippi Coastal Plain, to leverage grant funds and volunteer labor.

The bayou's wetland habitat had been seriously impacted over time. Its natural, meandering course was straightened, forming a steeply cut channel that degraded the bayou's function and aesthetic appeal. To reveal the site's social and ecological potential, the project reshaped the stream banks to create tidal marsh habitat and opened views into the constructed wetland. Local volunteers contributed over 3000 hours of service and participated in the construction of the project, removed debris, installed erosion control materials, and planted native plants.

The design studio engaged the local community and students through educational programs focusing on ways to improve the bayou's important functions including: 1) restoring and improving nursery habitat for fish and shrimp, essential to the local economy; 2) reducing pollution and debris entering the ocean through the integrated bayou and storm water system; and 3) creating marshland to contain floodwater from extreme storm events. Bayou Auguste has an important social role allowing the community to enjoy wildlife, encouraging environmental stewardship and appreciating the unique coastal environment that makes Biloxi home. Collaboration with the community resulted in a project in which both the process and the outcome increased community resilience by improving the natural water system and by increase environmental stewardship.

INFORMATION

Resilience comes from changing the way we imagine the future and acting on plans to alter and adapt to a future with increased risk. Information is essential to shape the imagination and make plans to become more resilient. Resilient information includes research to understand risks, vulnerabilities and actions to prepare for risks, information technology to help people comprehend and form values around resilience, and cooperative decision making efforts to apply information to plan alternatives.

Before "resilience" was such as well-used word, "sustainability" made a well-worn path, changing the way we think about how our current actions relate to our consumption of energy and impact human health and the environment. The costs of energy, health and environmental services impacted by our actions can be calculated and formulated with the costs of better systems, materials and practices. Thus sustainability has an economy that has successfully created a market. Resilience, on the other hand, depends upon a prediction of future loss and requires a more difficult calculation of how our actions today can reduce the cost of future losses. Resilience does not yet have a simple cost-benefit approach in the way sustainable practices, most of which save energy, have a predictable pay-back period. This complexity is because the background condition is changing because risks are increasing, but forecasts of how risks are increasing are complex and controversial. Therefore, resilience information is challenging and is often shaped by emotions. It requires a sort of faith that is more akin to traditional agriculture than to mechanical production. At the time of planting, the value of a future harvest is uncertain because it depends upon weather and the market; likewise, resilience is uncertain because it depends upon climate and the time-related effects and side effects of natural and human-made systems. Nevertheless, in the same way that twentieth-century agri-business counteracted the uncertainty of tradition agri-culture with a host of insurances and market controls, predicting and investing in future risks will undoubtedly improve as informational and predictive formulae advance, eventually replacing faith with global financing. In the meantime, however, especially at the scale of a city, resilience plans are moved by faith that actions taken today are worth the cost of uncertain future conditions.

The Gulf Coast Community Design Studio is working with resilient information at several scales. The smallest is the scale of a house. With the many houses that the design studio collaborated to design and build came expertise in building for hurricane hazards. During the rebuilding in the first few years following Hurricane Katrina the design studio developed wood frame construction details and sheer wall designs for dozens of houses. The architects and interns explained the structural rationale to many builders and building inspectors, since many of the builders were from parts of the country without high-wind zones and because the Gulf Coast municipalities well all getting to know the recently adopted International Building Code. In 2010 the Gulf Coast Community Design Studio worked in partnership with the Community and Regional Resiliency Institute to put on a training program. The design studio taught several classes about resilient wood frame construction to architects and builders. In addition they built full-size constructions of house framing showing framing, sheathing and finish.

In the first few years after Hurricane Katrina the focus was on high-wind construction as an engineering issue and there was not a national program to provide financial benefits to home owners. However, in 2010 the Fortified Home program was introduced from the Institute for Building and Home Safety (IBHS). The Gulf Coast Community Design Studio was well positioned to inform the community about this program and has been working with IBHS to educate and promote Fortified Homes. They are currently working with a partner organization to administer a homeowner assistance program for low-income families to be able to get a low-interest loan to make improvements that can save as much as 20% on their homeowners insurance. In addition to the work with IBHS the Gulf Coast Community Design Studio recently completed a project in partnership with the Federal Alliance for Safe Homes (FLASH) to produce a Resilient Home Building Guide. Such work directly informs design professionals, builders and homeowners about ways to make houses more resilient.

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Figure 4: Resilience Demonstration

DESIGN

Rebuild By Design is a national competition announced by HUD in the summer of 2013 to invite design teams to work in cities affected by Hurricane Sandy. The Gulf Coast Community

Design Studio was part of one of ten teams that were selected to participate in the design competition. As the name suggests the teams were given the charge to lead by design and to work with communities to come up with innovative proposals to address the risks that Sandy made apparent. It is significant in the national move toward resilience that the discussion around Sandy was noticeably different from the discussion in the years after Katrina. Resilience was the primary viewpoint of Rebuild By Design and proved to be an effective way to work with complex issues such as climate change and the vulnerability of aging infrastructure. The output of Rebuild By Design and the importance it placed on the role of design set a positive direction for architects, planners and landscape architects to take a lead in shaping the work of resilience.

The national move toward resilience was clearly made manifest by the fact that during the Rebuild By Design competition period HUD's Office of Sustainable Communities was renamed the "Office of Economic Resilience." Furthermore, the first major initiative of the Office of Economic Resilience was the National Disaster Resilience Competition (NDRC), which makes reference to Rebuild By Design as a model of how cities and states can do better than recover from disaster by using design and planning to imagine and pursue resilience. The Gulf Coast Community Design Studio is currently working with state agencies and other partners to assist the Mississippi Governor's office in the National Disaster Resilience Competition application. It is encouraging that even in a politically conservative state, working under the umbrella of resilience allows a multi-disciplinary group of scientists, planners, architects, economists, social service providers, and policy makers to work on challenging issues such as climate risk, shoreline loss, social and environmental vulnerability and land-use planning.

Resilient planning requires a realistic representation of a future with increased risk and illustrated ideas showing how these risks can be addressed. Thus, resilience is a design effort. But not done by architects alone; resilience planning is a collaborative design effort, bringing together people in the same way that disaster response and recovery brings people together. As illustrated in the work of the Gulf Coast Community Design Studio the current, broadly defined term "resilience" offers an extraordinary opportunity for universities to work in partnership with professionals to advance multi-disciplinary resilience efforts. Furthermore, if the output of university programs is seen as being relevant to government and to the general public their work can shape resilience's vague definition to include the value of design.

ENDNOTE

1. Governor's Commission on Recovery, Rebuilding and Renewal, *After Katrina: Building Back Better than Ever* (Jackson: Office of the Governor, 2005), 21.

Interscalar Design and Health Research Partnership: Research Integration Into Curriculum and Practice

Numerous built environment factors have a negative effect upon human health and wellbeing, including lack of natural daylighting, light trespass, poor air quality, poor water quality, damaging noise pollution, uncontrolled thermal conditions, constraints and limitations on physical mobility, disorienting surroundings, amongst others. A new vision for environmental health extends beyond the traditional removal of negative factors that cause illness and disease to embrace aspects of the built and natural environment that support physical health and emotional wellbeing.

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Our interdisciplinary team of biomedical, public health, integrative medicine, architecture, landscape architecture, and planning disciplines is conducting research at various scales to inform innovative concepts for addressing the interrelated physiological and biopsychosocial challenges. Novel correlations between health and wellbeing with built environment phenomena are particularly applicable for multiple aspects of design, including environmental quality, integrated natural systems, sensory environments, and safety. Integration of social connectedness and physical activity in design and urban planning are also implicated in this research.

The research framework presented here focuses on four significant aspects of this ongoing multidisciplinary effort: individual scale, community scale, building scale, and integrated outcomes for implementation of education and curriculum into practice. Primary physiological impacts of built environment factors upon health and wellbeing are documented at the individual level while biopsychosocial impacts are investigated at the community level with a focus on resiliency. These research results are implemented into academic design/build outreach practice for underserved communities, and also inform core fundamentals of environmental factors for dissemination in architecture curriculum technical courses.

Scientific correlations of biopsychosocial metrics to the built and natural environmental factors are made by quantifying pre- and post-occupancy studies to assess the impact of sustainable design on human physical and emotional health and wellbeing. An example of this approach is in our previous study showing that sustainable design positively impacted two different measures of physiological stress response.[1] The research is conducted by the use of non-invasive, unobtrusive mobile health devices and heart rate variability monitors, which allow for specific environmental attributes such as light (intensity, wavelength, glare, circadian rhythm), noise, temperature, airflow, etc. to be measured and correlated with physiological responses (stress and relaxation response) and psychological momentary experience sampling. The relationships between these health responses to environmental conditions are analyzed using Big Data Analytics to obtain time and locational attributes of both health and environmental data. The quantitative aspects of the research are cross-correlated with qualitative documentation of the designed environment affecting conditional responses in human health. Through parallel interscalar research investigations, the projected impacts of new knowledge surrounding health and wellbeing within the built environment will expand current paradigms for integrated design processes and methods. The innovative core of this research is the science of brain- immune-environmental interactions. The results of this research intend for the evidence needed to support holistic health and wellbeing in the design, construction, and maintenance of built environments. The critical position that these research activities assert is a prerogative for deep partnerships between biomedical and health professionals alongside those who design and steward the built environment.

INTRODUCTION

Basic principles of architectural design predominantly focus on ocularcentric aspects of human experience. Such cultural codes where sight prevails at the forefront of design thinking tend to suppress qualities of space and place for alternate sentient human experience. This facet of design theory is explored in the work of architect Juhani Pallasmaa through a phenomenological positioning. Pallasmaa situates the experience of architecture through more holistic concepts of sensation, including haptic and aural, in addition to the visual conditions of the environment.[2] Shifts in architectural theory towards encompassing phenomenology exemplify a contemporary mode by which human experience influences design practice and pedagogical methods engaged in design curricula.

The introduction of physiological and biopsychosocial human health measures in built environment research expands the potentials for deriving useful collective information for societal wellbeing. Our interscalar approach to research on built environment human health and wellbeing integrates both the individual and structuralist accounts, and will make use of the outcomes through codification of design principles for education and practice.

INDIVIDUAL SCALE

The World Health Organization's definition of health in the 21st Century states that health is more than the absence of disease.[3] It encompasses going beyond the traditional removal of negative factors that cause illness to embrace aspects of the built and natural environment that support physical health and emotional wellbeing.

A fundamental understanding of human responses to both positive and negative environmental factors is therefore important for design professionals to instantiate these principles into practice and to design environments for wellbeing at all scales.

It is well known that many aspects of the physical environment can either stress or calm. Broadly speaking, this includes all aspects of perception through each of the five senses – vision, hearing, smell, touch, and even taste. Activities also impact the stress and relaxation responses. Thus what one sees, hears, smells, touches and does in a space can all influence the brain and body's stress and relaxation responses.[4]

It is important to note that the brain's stress response is essential to life, and is the organism's main strategy to get out of danger, focus attention, and perform at peak. The goal therefore is not to get rid of stress, but to optimize the stress response to match the activity at hand. There is an "inverted U shaped curve" – and upside-down U that relates activity of the stress response to performance. At the far left of the curve one is totally relaxed and the stress response is tuned down very low – one is half asleep and not performing at peak. In order to perform at peak, the stress response needs to be turned on optimally. Performance fails when the stress response goes into overdrive, or lasts too long once the danger has passed.

Another important foundational principle is the role of the brain's stress response on the immune response: the science of the mind-body connection.[5] A wealth of research has established the many ways in which the brain and immune systems communicate. It is well known that chronic stress can prolong wound healing, increase susceptibility and severity of viral infections, speed chromosomal aging and speed cancer growth by impairing the immune system's ability to fight disease. This occurs through excess release of the anti-inflammatory stress hormone cortisol. In contrast, integrative medicine mind-body interventions, such as yoga, meditation, tai chi, exercise can all reverse the negative effects of stress on the body, optimize emotional and physical health and prevent disease. Social support is also important in health. On an individual basis, holding hands with a loved one significantly lowers the stress response and studies have shown that persons with a greater number of positive social interactions are healthier[6], while isolated individuals, especially the elderly are more prone to disease.[7]

Nature, or *biophilia,* is also an important stress reducer, where increasing numbers of plants in the environment and views of nature have been shown to significantly reduce stress and enhance the effects of activities, such as exercise.[8] Design professionals can help individuals fine-tune their stress response passively, simply by designing the built environment at all scales to stimulate or relax the senses, and to help foster healthy activities, such as exercise, meditation, and social support. This is familiar to all who have been to a spa, versus an airport or typical hospital.

Attributes of the built environment can have negative or positive effects on human health and wellbeing [Fig. 1]. Negative impacts include: lack of natural day-lighting, glare; noise; foul odors; uncontrolled thermal conditions; poor air quality; poor water quality; constraints and limitations on physical mobility, disorienting surroundings, amongst others. Positive

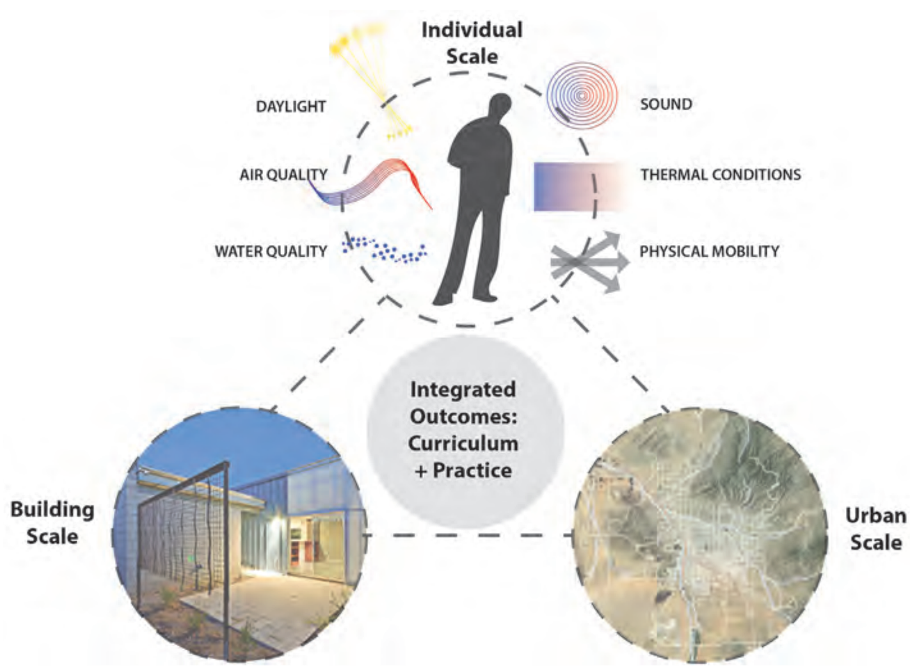

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Figure 1: *Interscalar Design and Health Research Integration Into Curriculum and Practice.*

impacts include optimal levels and qualities of light; optimal sound level, soothing music, nature sounds; controlled thermal conditions; way-finding; and areas for social support.

Our interdisciplinary team's research framework focuses on development of methods and technologies to sensitively measure the impact of many environmental attributes on human psychological, behavioral, physiological, and even molecular responses. These can be applied to quantify the impact of the built and natural environment on human responses at all scales: individual, building, and community scales.

Scientific correlations of biomedical metrics to the built and natural environmental factors are made by quantifying pre- and post-occupancy studies to assess the impact of sustainable design on human physical and emotional health and wellbeing. The research is conducted by the use of non-invasive, unobtrusive mobile health devices such as heart rate variability monitors, which measure the balance between the two components of the nervous system that detect the stress and relaxation responses – the sympathetic (stress) and parasympathetic (relaxation) responses. The latest generation of such monitors also detect activity, posture, sleep quality and even altitude at such sensitive levels that one can detect whether a person is climbing stairs. Other devices can be used to measure psychological responses, so-called momentary experience sampling. Data from such mobile devices can be used to track the human experience in real-time and real-place. Eventually new technologies will allow such data streams to be linked to specific environmental attributes that the person experiences, such as light (intensity, wavelength, glare, circadian rhythm), noise, temperature, airflow, etc. The relationships between these health responses to environmental conditions are analyzed using Big Data Analytics to obtain time and locational attributes of both health and environmental data. The quantitative aspects of the research are cross-correlated with qualitative documentation of the designed environment affecting conditional responses in human health.

The goal of developing such quantitative methods is to inform design principles to optimize the built environment for health and wellbeing. We are at an exciting juncture in the fields of design and mobile, personalized health, where the data gleaned from such tools will help design professionals optimize their designs for health and wellbeing, instantiating the World Health Organization's goals of viewing health as far more than the absence of disease, and encompassing the impact of all aspects for a person's environment in their health.

COMMUNITY SCALE

Planning engages multiple scales of activity external to physical structures themselves. Research at the University of Arizona will reshape the curriculum and ultimately practice as it relates to the nature of urban form from the neighborhood to the regional scales. It begins with modeling dimensions of urban form. It continues with identifying opportunities to reshape the built environment at all scales through interventions in the life cycle of structures and built landscapes.

The point of departure for urban form research is recent work by Reid Ewing and Shima Hamidi (2014)[9] published by the National Cancer Institute: *Measuring Urban Sprawl and Validating Sprawl Measures*.[10] They modeled four dimensions of urban form to create an overall index of urban sprawl—which is recast as the Ewing/Hamidi Urban Form Index below. Those dimensions and their component parts are:

Density

1. Gross density of urban and suburban census tracts;
2. Percentage of the population living at low suburban densities (less than 1,500 persons per square mile);
3. Percentage of the population living at medium to high urban densities (between 1,500 and 12,500 persons per square mile);

4. Urban density based on the National Land Cover Database; and
5. Gross employment density of urban and suburban census tracts.

Mixed-Use

1. Countywide average job-population balance (jobs/population);
2. Countywide degree of job mixing (based on an entropy model); and
3. Countywide average Walk Score. [11]

Centering/Agglomeration of Activities

1. The coefficient of variation in census block group population densities, defined as the standard deviation of block group densities divided by the average density of block groups (where the more variation in densities around the mean, the more centering and/or subcentering exists within the county); and
2. The coefficient of variation in census block group employment densities, defined as the standard deviation of block group densities divided by the average density of block groups (where the more variation in densities around the mean, the more centering and/or subcentering exists within the county);
3. Percentage of county population in CBD or sub-centers; and
4. Percentage of county employment in CBD or sub-centers.

Street Accessibility

1. Intersection density for urban and suburban census tracts within the county, excluding rural tracts with gross densities of less than 100 persons per square mile; and
2. Percentage of 4-or-more-way intersections, again excluding rural tracts.

Ewing and Hamidi summed the individual scores which has the effect of giving each component within each respective dimension equal weight, then giving each dimension equal weight (25 percent each) in calculating an overall raw score.[12] They then transformed the overall score into an index having a mean of 100 and a standard deviation of 25 (similar to the Stanford-Binet intelligence quotient score). More compact landscapes have index scores above 100 (see the left panel in Figure 2—Arlington County, Virginia in this case) and more sprawling ones have scores below 100 (see the right panel in Figure 2—Oglethorpe County, Georgia, for example).

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Figure 2: *Continuum of Compact and Sparwling Urban Form Conceptualized.* (Image: Ewing and Hamidi, 2014)

We have tested the Ewing/Hamidi Urban Form Index[13] in a variety of applications and find it rather robust. For instance, in using it as a predictor (among many control variables) for change in metropolitan- and county-level job change between 2000 and 2010 (meeting all relevant statistical tests with a large coefficient of determination), elasticity outcomes indicated that a 10-percent increase in the Urban Form Index increased jobs by 0.6-percent, which is nearly the same outcome measured in different ways by two independent teams of econometricians. A team of University of Arizona researchers is being assembled to propose research that applies the Urban Form Index to a variety of public health concerns at metropolitan, county, and neighborhood scales.

This research will help advance the use of scenario planning whereby outcomes to alternative urban forms resulting in higher Urban Form Index scores can be estimated to help guide long-range planning to achieve preferred public health and other outcomes through explicit changes to urban form.

We have pioneered methods to estimate when different types of the built environment may become opportunities for redevelopment from the level of the parcel to an entire metropolitan area.[14] For instance, over the next 30 years more than half of all nonresidential structures and up to a fifth of all residential structures in growing metropolitan areas will be torn down and replaced, repurposed through substantial rehabilitation, or in other ways recycled. Using a parcel-based analysis allowing for assembly of parcels to different scales, planners can identify when large segments of commercial corridors, neighborhoods, nodes or other landscapes may become opportunities for redevelopment at about the same time. We have also developed models to help understand the timing of market-driven redevelopment where markets are currently unable to justify such redevelopment. These tools calibrate the nature of public-sector intervention needed to accelerate redevelopment so that the built landscape may be reshaped earlier than later to achieve broad public policy objectives during a planning horizon.[15]

The next logical step is to merge the Urban Form Index with models to facilitate the interscalar reshaping of the built environment so that redevelopment decisions are made with improved appreciation of benefits. The merging would occur after research demonstrates the utility of increasing the Urban Form Index score substantially through the redevelopment process in ways that improve public health, economic, quality-of-life, and related outcomes. Once the calibration is done, the Urban Form Index can be merged into scenario planning packages such as *Envision Tomorrow Plus*.[16] The merged models can then be included in planning and design-based curriculums to better inform the next generation of practitioners on the benefits of alternative designs of the built environment at widely varying scales.

BUILDING SCALE

The University of Arizona School of Architecture engages students with design-build projects through the Drachman Design Build Coalition (DDBC), an entity that identifies local sites in Tucson for single-family affordable housing development to execute design, construction, and post-occupancy activities. This design-build outreach component of the professional architecture curriculum allows for both the integration of research in application as well as the translation of classroom learning into practice.

While most DDBC structures are developed with innovative building technologies, including alternative construction materials and methods for passive environmental performance, more recent DDBC houses will integrate outcomes from the human health and wellbeing research to inform unique design strategies [Fig. 3]. Fundamental attributes for human health in built environment design, including natural daylighting, sound control, thermal conditions, as well as air and water quality measures, are established as guiding principles for future design development and post-occupancy analysis studies of DDBC houses. Prior DDBC projects formalized research outcomes for energy and water conservation strategies in affordable housing design, which will continue to be valid and progressed for further development towards net-zero energy and net-zero water dwellings. However,

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Figure 3: *DDBC Affordable Housing Integrating Fundamental Attributes for Human Health and Wellbeing.* (Photos: L.Frederick)

additional focus for research in DDBC projects will equally emphasize modes for measuring effectiveness of the designs for health benefit.

The DDBC projects also negotiate the community scale public health research by means of assessing potentials for infill sites and determining optimal setbacks, building form, and programmatic relationships as contextual response. The site availability for affordable housing projects can be burdened with particular environmental challenges that enhance the necessity for addressing human health and wellbeing in such conditions through the design and construction techniques. For instance, some of the sites available for these projects may be located adjacent or near Industrial zoning, where noise and air pollution may prevail. Other sites for affordable housing projects may be zero-lot line infill conditions with limited access to adequate daylight.

In addition, particular tools and methods are currently being developed to measure and analyze building-scale design concepts against integration of health and wellbeing attributes prevalent in such environments. These methods include the analysis of design attributes for interior habitable spaces of digital models and built spaces with fisheye lens photographs and evaluative tools [Fig. 4].

By establishing 360-degree view-factor images of a human individual's interface with the interior environment, metrics can be calculated for the quantification of particular environmental attributes that can significantly impact human health. The view-factor calculations of these attributes may include natural daylight exposure, exterior views, bright materials, dark materials, plants, etc., and are intended to provide baseline relevance of spatialized influence upon human experience. The integration of design factors specific for human health at the building scale is thus accurately documented for correlation with the individual metrics of human stress response and localized environmental sensing. This methodological framework stitches together building-scale factors as causal measures influencing environmental data (such as photometric, air quality, noise vibration, and thermal conditions) against individual-scale measures based upon heart-rate variability and stress response. This framework inserts both the human's response to spatial and material design qualities as well as environmental conditions to inform building scale principles.

INTEGRATED OUTCOMES FOR CURRICULUM AND PRACTICE

Cross-linking the individual, building, and community scales of human health and wellbeing research in this interdisciplinary effort is informing a series of emerging concepts applicable for design fundamentals. The significance of the individual scale research informs the biophysiological responsiveness to environmental design attributes for optimal human wellbeing that encompasses physical, emotional, and mental aspects functioning from a phenomenological positioning. The significance of the community and urban scale research informs both physical mobility and social connectedness design attributes for broader public health, functioning from a structuralist positioning. The significance of the building scale research offers a negotiation between the spectrum of individual and collective human experience and physiological response. The building scale addresses the health of

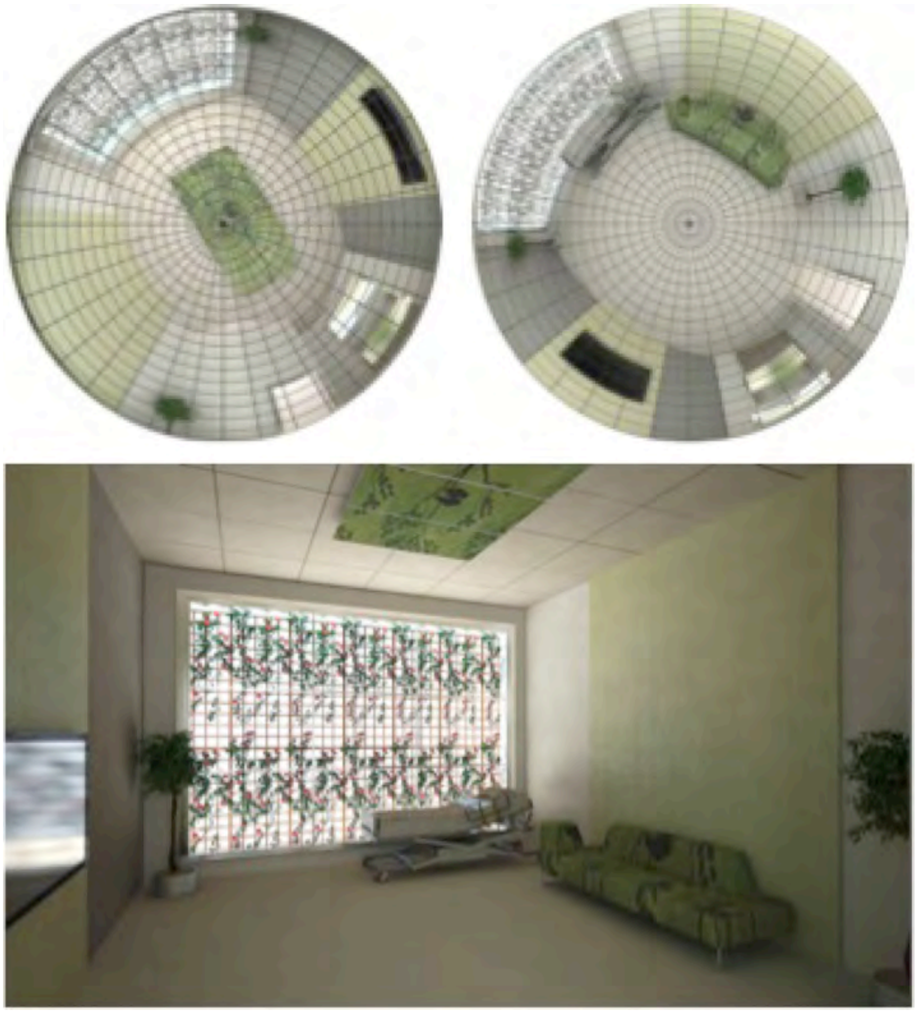

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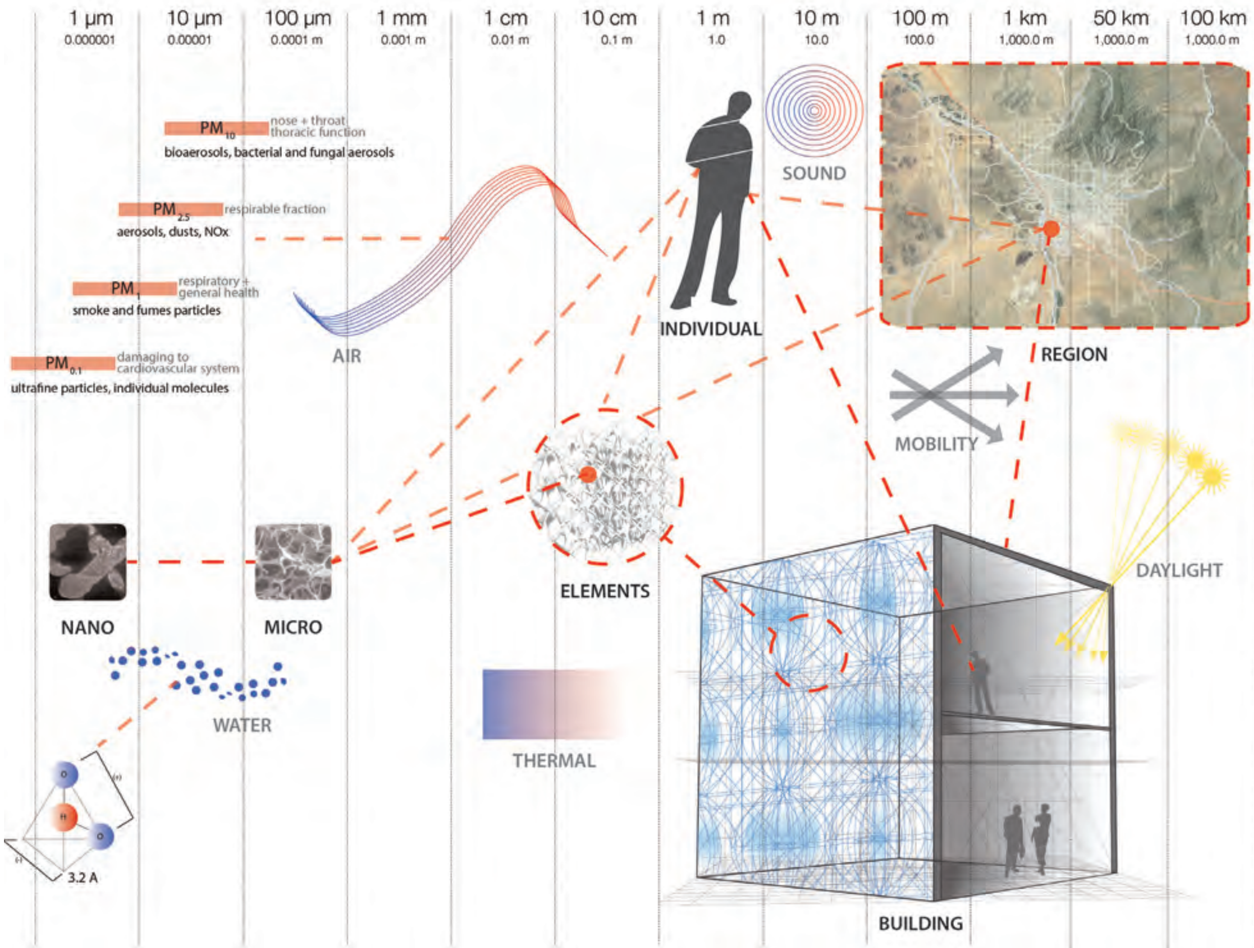
Figure 4: *Fisheye View-Factor Calculation Method for Design Integration of Wellbeing Attributes.* (Images: G. Shirazi)

individuals essentially through the choreography of environmental phenomena by means of organizing materials, space, and form. The building scale also addresses the health of communities through both site selection for a given program and volumetric morphology relative to surrounding context and broader density variables. Each scale of research is cross-linked to merge individual and societal human wellbeing benefits into fundamental design principles and application in building design [Fig. 5].

Aspects of the interscalar research outcomes are providing fundamental knowledge areas on human health and wellbeing for built environment design. These outcomes primarily consist of:

1. Science of brain-immune-environmental interactions to inform primary attributes of design strategies;
2. Strategies for improved public health at regional and neighborhood scales resulting from Urban Form Index metrics;
3. Design methods integrating human health and wellbeing attributes in development and configuration of material, space, and form.

Each of these primary outcomes is being translated into fundamental design principles that are introduced in the architecture curriculum through core environmental courses. The design principles emphasize the relationship between environmental phenomena, such as light, air, and sound, to the correlated effects on human experience and benefit. While basic



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environmental physics is well established in design research, correlations to human health response begin to inform alternate implications for spatial and formal manifestations.

0In addition, core fundamentals and design principles for urban form and regional development patterns are established through Urban Form Index metrics to improve public health and quality-of-livability influencing greater societal wellbeing. These community scale programmatic and morphological design principles are introduced in urban design and planning curriculum, as well as in the sustainable built environment courses. These fundamentals also find their way into practice through the outreach activities of our College of Architecture, Planning, and Landscape Architecture, including technical assistance provided to underserved communities facilitated through the college's Drachman Institute.

Our interdisciplinary research team is also an active member of the American Institute of Architect's Design and Health Research Consortium that was inaugurated in January 2015. The partnership established through this consortium is allowing for the opportunity for our human health and built environment research findings and the resultant design principles to be shared with the broader professional design community. The integrated outcomes of the interdisciplinary research directly inform a collective resource influencing living practitioners and policy-makers in future built environment design decisions.

Figure 5: *Interscalar Health Attributes for Built Envrionment Design Integration.*

GOALS AND FUTURE WORK

The goals for facilitating the ongoing and projected human health and wellbeing interdisciplinary and interscalar design research into curriculum and practice concurrently address:

1. Establishing the methods for cross-correlating human health response to environmental factors with the specifics of building form, space, and material composition as experienced by the individual;
2. Establishing the methods for correlating Urban Form Index public health and livability metrics with community design principles as determinants for collective wellbeing experience;
3. Translating the quantifiable outcomes from these innovative methods to new baseline knowledge informing design principles in the architectural and community/urban design process;
4. Integrating these design principles for health and wellbeing in core fundamental teaching in professional architecture and sustainable built environment curriculum;
5. Applying these core principles in the design and construction of DDBC affordable housing projects for ongoing evaluation and monitoring;
6. Applying these core principles in the planning projects and efforts through the college's Drachman Institute outreach arm; and
7. Introducing these core principles to the broader professional design and policy context through active participation on the AIA Design and Health Research Consortium.

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14. Arthur C. Nelson. *Reshaping Metropolitan America*. Washington, DC: Island Press, 2013.
15. Arthur C. Nelson. *Foundations of Real Estate Development Financing: A Guide to Public-Private Partnerships.* Washington, DC: Island Press, 2014.
16. Arthur C. Nelson helped lead a team of researchers at the University of Utah to create *Envision Tomorrow Plus* as a sophisticated, open-source scenario planning tool that is changing long-range land use planning nationally. See http://www.envisiontomorrow.org/about-envision-tomorrow/.

Mass Timber Design Research at the Nexus of Practice and the Academy

Mass timber's composition and manufacturing processes enable mass-customizable building assemblies for performance-based design. In addition to architectonic appeal, mass timber construction offers an array of societal benefits ranging from 1) improving forest management and health, 2) increasing rural economic development, and 3) providing a locally sourced, low-carbon construction material.

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INTRODUCTION

Mass timber is an emergent building assembly technology that advances themes of prefabrication, modularization, parametric design, and renewable materials in architectural practice and education. Mass timber is a collective term for several engineered heavy panel wood products including cross-laminated timber (CLT), nail-laminated timber (NLT), glued laminated timber (GLT) laminated veneer lumber (LVL), laminated strand lumber (LSL), and parallel strand lumber (PSL). Mass timber's composition and manufacturing processes enable mass-customizable building assemblies for performance-based design. In addition to architectonic appeal, mass timber construction offers an array of societal benefits ranging from 1) improving forest management and health, 2) increasing rural economic development, and 3) providing a locally sourced, low-carbon construction material. Washington State University (WSU), as the land-grant institution for the State of Washington, has taken a lead role in the research, development, and adoption of this emerging technology in the Pacific Northwest. This paper explores mass timber methods utilized and knowledge generated from two design research activities related to teaching at the Academy and application with Practice.

The WSU Institute for Sustainable Design (ISD) – a collaboration between two design and engineering teaching units and one material science and engineering research unit in the WSU Voiland College of Engineering and Architecture – has developed two synchronous design 'vehicles' to drive innovation with mass timber efforts: a studio course called the Integrated Design Experience (IDX) to conduct teaching activities and the Integrated Design Lab (IDL) to conduct research and outreach activities. IDX and IDL connect design thinking models of studio instruction in architecture with funded research and stakeholder outreach projects in engineering and the sciences at WSU. Allied sponsored research projects have included the design of pilot supply chains for biofuels and coproducts from forest residuals (USDA-NIFA Competitive Grant no. 2011-68005-30416, $40M awarded, IDX 2010-2016), mass-customization of hybrid CLT panels (USDA-NIFA Competitive Grant no. 2013-05984, $264k awarded, IDX 2014-2015), design and engineering of tall wood buildings (USDA

Tall Wood Competition, finalist, $2.4M proposed, IDX 2014-2015), and CLT manufacturing and supply chain technomarket analysis in the Pacific Northwest (USDA-FS-WERC 2015 Competitive Grant, $250k awarded + $394k cost share with partners, IDX 2015-2017). The two integrated design vehicles (IDX + IDL) bridge gaps between Practice and the Academy while enabling an appropriate level of creative autonomy necessary to drive innovation in complex, wicked problems such as the development and adoption of mass timber systems.

SCHOLARSHIP OF DISCOVERY

Like all mature institutions, Practice and the Academy share inherent resistance to change. Traditions are valued, tested, and slow to evolve. Yet, both institutions take pride in innovation; in the ability to not only discover new knowledge, but to do it with unique methodologies. French philosophers Gilles Deleuze and Félix Guattari differentiated between the slow 'striated space' of institutionalized apparatuses and the fast 'smooth space' of the in-between (Deleuze and Guattari, 1987). They argued that inhabitants of smooth space are 'nomads' that innovate to disrupt institutional apparatuses. For individuals, ideas and initiatives that inhabit existing institutional striations opportunities to innovate are limited without extraordinary measures or energy. When these excited states happen, ideas deterritorialize and become 'nomads' within smooth space allowing innovation to develop. Eventually, these innovations are incorporated into the bounds of institutional striations and define new norms. As both Academia and Practice take on the wicked problems of our age, it becomes imperative to find ways to innovate (Brown and Harris, 2010).

Designers solve 'wicked problems' – problems where both the solution and the path towards and solution are unknown (Buchanan, 1992). Designers rely on and are comfortable with iterative processes of ideation and application to accomplish this. For architects, these processes are hard wired from academic studio training and lead to innovation and discovery on projects. However, hard wiring this process in actual institutional structures remains challenging.

This paper proposes that the integrated design vehicles of IDX and IDL at Washington State University enable these nomadic challenges and opportunities between the striations of academic-based teaching apparatuses and practice-based application apparatuses (Figure 1).

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SCHOLARSHIPS OF TEACHING AND APPLICATION

The Academy and Practice exist within a spectrum between teaching and application. Professional practitioners of architecture typically emphasize application while schools typically emphasize teaching due to the inherent contexts each exist in. Each seeks their own appropriate balance between teaching and application. Formal mechanisms to achieve this balance are necessary when rutted in deep institutional striations. Architects in Academia and Practice exercise many mechanisms to momentarily break out of these striations (to deterritorialize per Deleuze). These moments offer important freedom or divergence from the rigid task at hand to facilitate creative leaps and contemplation – core elements in design thinking and ideation (Cross, 2006). Examples of these mechanisms include

Figure 1: Scholarship Framework

charrettes, competitions, and scholarly design activities of writing, drawing, and modeling. These divergent activities are uniquely bi-directional equally pulling academics towards application and practitioners towards teaching – blurring ownership of either scholarly activity to the Academy or Practice. Methods in IDL and IDX attempt to not only utilize these mechanisms, but to also teach the underlying design theory.

TEACHING METHODS: IDX

The Integrated Design Experience (IDX) is envisioned as a studio-based teaching mechanism between siloed disciplines within Washington State University seeking solutions for grand built and natural environment challenges (Figure 2). Projects within IDX have ranged from the ideation and design of a data-driven organic farm, building and infrastructure design for Washington State ferry terminals, building and industrial site design for a regional biofuels supply chain, and most recently building and assembly design for mass timber supply chains, the topic of this paper. Projects undertaken in IDX share certain common features. First, the complexity of the problem requires interventions at a range of scales from the region down to the human. Second, the problems touch several disciplines which require collaboration in order to innovate. Finally, the problems have near-term practical applications. This last feature is a significant factor in the ability to reach out to industry and professional partners for interest and support. This outreach also addresses the land grant mission of Washington State University.

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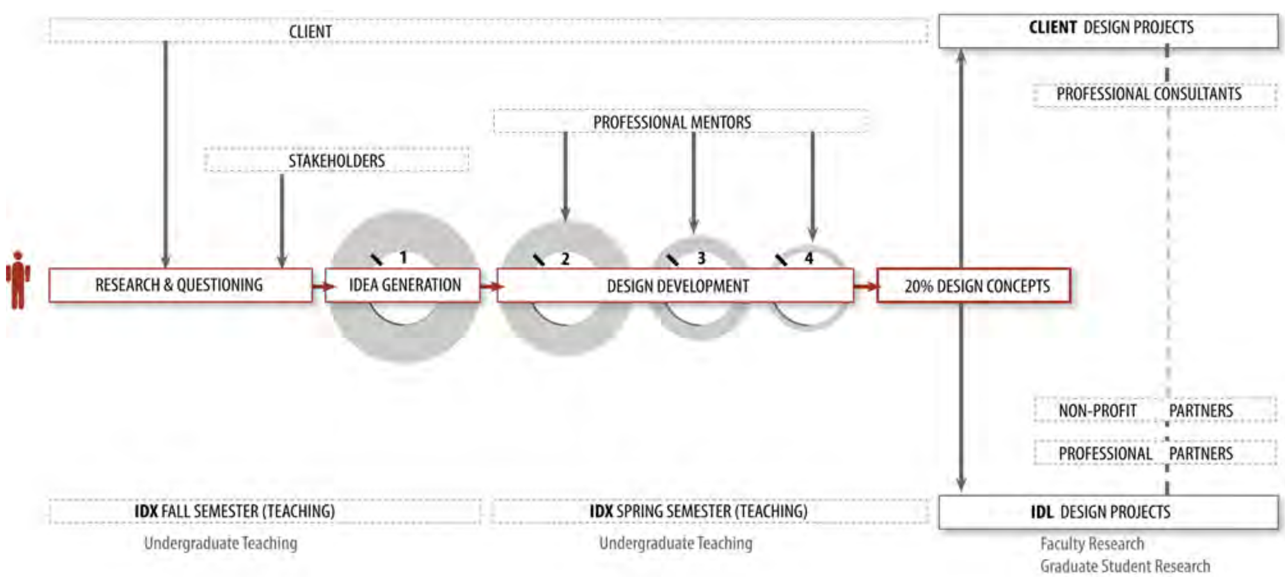

IDX courses generally consist of a core college-wide elective course and allied departmental courses. At times the research being conducted in the core course does not directly align with the curricular needs of a given discipline participating. In these situations, the allied courses are spun off to allow for focused teaching that fulfills curricular needs yet address themes related to the research problem. The outcomes of these allied courses may not directly address the fiduciary responsibilities of the sponsored research, yet they provide valuable perspectives and engagement by students and faculty for the current project and for future research development.

A key component in the IDX model is the integration of professional mentors into the studio experience. These mentors are engaged early in the studio as the project is introduced and then at strategic points during the semester for student feedback. These engagements take

Figure 2: Integrated Design Model

place face-to-face and via videoconference. The practical perspective of the professional mentors tempers the trajectory or student ideas while at the same time the mentors are exposed to new ideas, thus altering their perspectives as well. The end product for the studio is envisioned as a fully formed innovative idea that shows promise for application and is ready for handoff to professional partners for further development (Figure 3).

The premise of the core IDX course is to provide the students the skills, infrastructure, and setting to apply design thinking methods in order to develop innovative insights and solutions with respect to the research topic. The course is modeled on the design studio model. For most non-design students, design thinking and the studio mentorship model are new approaches to problem solving.

The design thinking method and the design studio model ask participants to engage in a nonlinear iterative process where the outcome is an emergent condition. The (often) unpredictability and range of outcomes are the method and model's strength in this setting. Often, students outside the design disciplines find it unsettling that there is not a clearly defined checklist or formula to be applied to arrive at a singular solution. A good deal of care and mentoring are needed to get them to the point in which they are confident enough to really explore possibilities. The inherent one-on-one interaction between student and instructor of the studio model is ideal to overcome this initial hurdle. Having design students collaborate also eases the transition significantly because they are familiar with the design studio model and design thinking methodology.

In addition to learning design thinking, students are exposed to project infrastructure consisting of a rigorously organized asset management protocol, graphic standards, and numerous software/hardware assets. A series of workshops are used to introduce the students to the knowledge and skills required for research methods, documentation skills, diagramming, GIS, graphic design, and parametric design among others. Students learn several new software applications. For many it can be daunting at the beginning, but they quickly help each other get up to speed.

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The IDX course/studios begin by introducing the students to the context and scope of the research topic by experts from both academia and professional spheres while simultaneously learning software and design thinking methodologies. This is followed by a group research phase with the goal of each group being able to provide peer expertise in a specific topic throughout the course of the studio and to produce base assets such as diagrams, bibliographies, and inventories which will be used throughout the semester. The students then engage in brainstorming and charrette exercises to identify early innovation trajectories

Figure 3: IDX Student Work, Brian Dorsey

for further exploration. Another round of research related to the trajectories is undertaken before the groups begin developing their innovations further.

The 2014-2015 IDX Mass Timber studio paralleled the development of a WSU entry to the USDA Tall Wood Competition with professional architecture, engineering, construction, and building operations (AECO) partners including Miller|Hull (architecture), Arup (structural and fire engineering), Berg (manufacturing), McKinstry (mechanical and electrical engineering), and Sellen (construction). The students engaged the same site and programmatic criteria as the professional team. Because of confidentiality agreements with the competition sponsors, the team could not share specific results with the students. However, Miller|Hull architects participated in design reviews of student work. As the Principal Investigator was also an instructor for the course, information was exchanged in terms of analysis, programming, and structural strategies.

A conceptual design framework was developed that was easy to understand and implement with computational design tools used in the course. The framework provided students methods to break down the design problem into discrete parts and to oscillate between general and specific concerns while iterating through design solutions. The framework consisted of three categories: Intent; Method, Outcome. Students began by capturing their design intent by elaborating a set of principles, general statements of performative intent with multiple possible solutions, and rules, specific prescriptive objectives with singular solutions. This was followed by methodically interpreting the previous statements of intent into systems of parameters. Students were encouraged to engage in the difficult (perhaps impossible) translation of qualitative properties into quantifiable systems while also researching real world ranges and data for quantifiably direct parameters. The completed parametric system formed the 'genes' of the team's building, its 'genotype'. By varying the inputs of the parameters individual instances of the building, 'phenotypes', were generated. This method allowed students to explore significant numbers of design permutations and also to implement evolutionary solvers to cull permutations for specific design criteria.

Student computational design and tool knowledge levels varied significantly. To overcome this, students were taught basic computational thinking without using any tools. To create a solid foundation emphasis was put on breaking down problems into discrete parts (functions) that were defined and elaborated as 'pseudocode', just basic english sentences describing the process step by step. This allowed the students to focus on their intent in focused ways and without worrying about implementing them with the computational design tools they were unfamiliar with. Later they used these to implement them computationally.

Integrated student teams (architecture, structural engineering) used the above framework and computational design tools and methods to perform site and program analysis in parallel to the professional team. The students collaboratively developed baseline 'genotype' parametric building models that responded to site, climate, program, and structural patterning in pre-design. Engineering students developed parametric analysis tools for evaluation of iterative structural decisions. Architecture students further developed conceptual designs representing multiple phenotypic models that emerge from the collaborative genotype programming.

The development of the group genotypes in the fall semester allowed the students to quickly develop their own individual projects (phenotypes) within a short time span and to achieve a level of detail that enabled them to transfer their parametric models into Revit for development of technical drawings. The workflow between Rhino/Grasshopper and Revit was an area that took significant technical investigation to find the the appropriate set of tools and set appropriate expectation levels for the technology as it stands at the moment.

Undertaking these activities uncovers the need for new tools, but also contributes to the development and refinement of existing tools and workflows. Collaboration with practitioners is important in order to hone these tools and techniques for application in real world scenarios and workflows. The computational methods and tools used in this studio to analyze and explore design possibilities have not become the norm in architectural practice, but their holistic integration by SHoP Architects and exploration by research studios such as LMN's Technical Studio and others suggests wider adoption will come sooner rather than later. The conceptual design framework developed for the class offers one possible entry point for wider adoption of computational design within architectural and structural engineering firms that would like to experiment with use of computational design tools and techniques.

It is also advantageous to the engineering profession to have future employees being introduced to not only the way designers of the built environment approach problem solving but also the computational tools and methods used to create the solutions. The engineering students were quick to grasp the power and utility of Rhino/Grasshopper visual scripting. The ability to move analysis such as seismic design out of spreadsheets and into a visual realm of 3D modeling was powerful. Engineering students created algorithms for calculating and visualizing building and assembly-scale characteristics like centers of rigidity. Engineering and architecture students were able to see real time responses to changing parameters to collectively understand the implications of their design decisions.

In professional practice there is always a tension between the needs of practice today and projecting the needs of practice five to ten years into the future. Not all practices have the financial ability to create in-house research studios. By partnering with the Academy, practitioners can help develop the discourse and tools of future practice while also contributing to the preparedness of students for future employment. It is the belief of the authors that one role of the Academy is to project the future state of practice and to develop tools and students that define that future state while also having strong fundamentals for practice today. As a land grant institution, WSU cannot stop at just projecting these future states and preparing students. It must also facilitate the application of new materials, tools, and methods in practice. The Integrated Design Lab is the vehicle designed to accomplish that task.

APPLICATION METHODS: IDL

To accelerate design and manufacturing market adoption of mass timber systems, the Integrated Design Lab (IDL) compliments the student teaching model of IDX by conducting research and outreach activities with industry and professional practice partners. The State of Washington (and the Seattle metropolitan area in particular) is served by progressive and innovative professional architecture and engineering practitioners competent to engage and apply discovery initiated in academic studio and labs. To facilitate this engagement, the IDL provides technical design assistance and market diffusion activities to professional AECO teams as part of an allied regional network of university labs in Spokane (Washington State University), Seattle (University of Washington), Portland (University of Oregon), Boise (University of Idaho), and Bozeman (Montana State University). The network seeks to transform design, construction, and building operational practices to advance high-performance building designs that are more comfortable for people, require less carbon and energy to construct and maintain, and enhance the health and productivity of inhabitants. Digital modeling, analysis, and fabrication methods tested with faculty and students in IDX are applied to real-world projects. Innovations from the IDX studio are advanced to formal commercialization and tech transfer outlets and inform methods necessary to integrate disparate concerns of stakeholders across entire mass timber supply chains from forest to building site. Market diffusion of mass timber systems in the United States requires holistic

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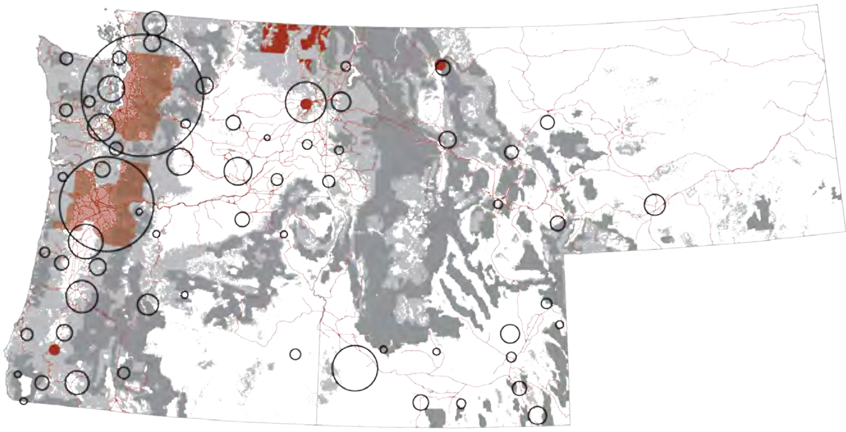

integration of cradle-to-gate manufacturing with the design, engineering, and construction of buildings. To accomplish this, the IDL has developed strategic supply chain partnerships including a lumber producer, an industrial CLT manufacturer, and a digital fabrication and systems integrator to complement existing WSU partnerships with the AECO (architecture, engineering, construction, and operation) community primarily in the metropolitan Seattle and Spokane market areas. Many of the manufacturing and design partners collaborate in the student and teaching faculty activities of IDX. IDX provides an entry point for engagement with academinc design research initiatives which often leads to deeper commitments with sponsored research or competition activities of the IDL. This engagement is critical for universities to gauge relevance of research activities with practice and to gain cost share commitments often necessary to secure grants.

IDL manufacturing efforts are aimed at delineating needs of a key existing gap of prefabrication of mass-customized panel assemblies utilizing digital fabrication and advanced manufacturing technologies. This step in the supply chain moves construction activities into the mills and factories thereby facilitating rapid on-site construction and transfer of value up the supply chain to the lumber and manufacturing sectors. Addressing this gap has additional value of strengthening the role of AECO teams in the manufacturing process. While prefabrication concepts have a deep history in architecture, meaningful realization of prefabricated mass-customized building assemblies has been strengthened with the emergence of digital modeling and manufacturing processes.

In addition to the technically savvy AECO teams, the IDL utilizes digital methods of parametric design and digital manufacturing with traditionally analog partners in mature industries such as lumber milling and lean manufacturing. This broad technomarket integration brings AECO teams closer to realizing *Refabricating Architecture* (Kieran and Timberlake, 2004) ideals. These wide-ranging concepts from mass timber assembly-scale design to supply chain design were born in the IDX studio environment. The incubation in IDX and focused development in IDL led to successful federal USDA forest product and wood innovation grant proposals that support sponsored research and teaching activities related to technomarket analysis of CLT supply chains and design application. This research considers multiple economic, environmental, and human-centric factors in the design of building typologies across multiple sectors including commercial, housing, and industrial uses. This holistic approach to building design engages architecture and engineering practitioners in the Pacific Northwest seeking a high level of sustainability and performance-based design (Figure 5).

Figure 4: PNW Forest Resources and Urban Markets

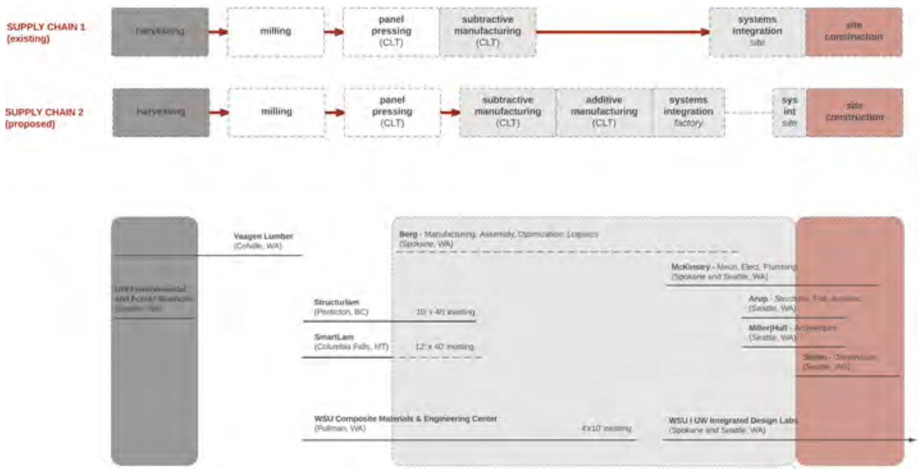

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Figure 5: Mass Timber Supply Chain Scenarios and Partners

FUTURE

The structure of IDX and the IDL was created to provide Practice and the Academy the tools, techniques and opportunity to overcome their ‘striated spaces’ and become deterritorialized nomadic innovators in the words of Delueze and Guatarri. Within IDX, exploration of new tools and the development of new frameworks and methods developed in collaboration with practitioners equip students to be inventive future practitioners prepared to tackle the grand challenges that await them. Complimentary design research activities in the IDL deeply engage partners across the entire wood industry to develop cutting-edge holistic cradle-to-gate systems for utilizing our renewable wood resources in the creation of our built environment.

Future IDX studios will continue to advance emerging concepts at the intersection of practice and the academy to explore multi-scalar aspects of mass timber design utilizing computational design and digital fabrication including: supply chains and life cycle assessment (regional scale), multiple typologies (building scale), high-performance seismic connections tunable for specific performance characteristics (assembly scale), and macro 3D printing methods with wood (material scale).

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Dynamic Composite Cladding

Dynamic Composite Cladding is a collaborative research project that attempts to recast typical low cost cladding as a high performance, customized system.

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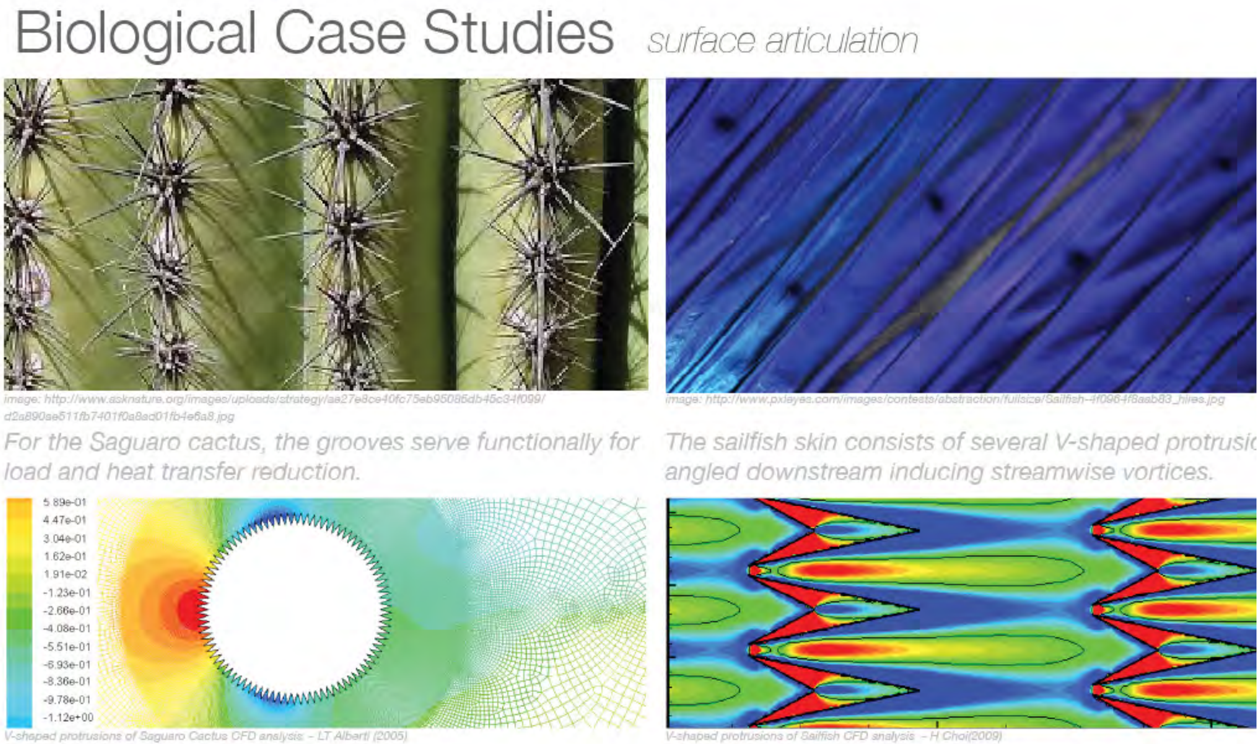
INTRODUCTION

Dynamic Composite Cladding is a collaborative research project that attempts to recast typical low cost cladding as a high performance, customized system. The focus of this research is to produce a next generation cladding system that departs from the conventional environmental and aesthetic thinking for a building facade. The composite cladding is designed to be a dynamically responsive yet inert facade system with a very low cost of production and installation. While the primary challenge for the system may be understood as being an environmentally responsive wall assembly without mechanical actuation — the aesthetic 'performance' is positioned as an equal priority by applying complex visual design logics as surface topology.

The research emerged out of a partnership established between an advanced composites manufacturing company, an architecture firm and the academy. The tripartite relationship has been critical in the effort to actualize the project and test on two buildings and one interior to date. Students, research/practice faculty and the architecture firm worked with the manufacturer to develop proprietary material compositions, layup schedules and molds for each custom application. The architecture firm worked with the manufacturer and students to understand economies and satisfy client concerns while achieving the diverse and often times competing goals. This progression of research and student collaboration includes several various stages of experimentation ranging from undergraduate course research to graduate research assistantship studies to internships within architecture firms.

BACKGROUND

Towards the end of the twentieth century computation began to be utilized within the discipline of architecture in a number of ways; however, it was not until late in the century when computation begin to emerge as a tool for analyzing building performance during the design process. Within this trajectory, only recently has the availability of computational power reached a point to which Computational Fluid Dynamic (CFD) simulation could be widely used to analyze performance at building scale. Here the early building CFD studies



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primarily focused on the macro building geometry with a focus on tall building performance primarily to study load shedding. To a lesser degree there were some secondary studies focused on interior airstream simulations in relation to human comfort. However, at the very end of the 20th century interest in how surface articulation affected building performance in the airstream began to emerge as an area of inquiry. Research published by Maruta, E., M. Kanda, and J. Sato (1998)[1] for example examined the effects of surface roughness on building performance at the end of last century. More recently, studies have been undertaken focusing specifically on how elements such as balconies affect building performance in terms of loading and energy performance as described by Lignarolo, Lorenzo, Charlotte Lelieveld, and Patrick Teuffel(2011)[2] and H. Montazeri, and B. Blocken (2013)[3].

In other fields of inquiry the relationship between surface roughness and issues of performance have been studied for some time. Perhaps most famously is how a shark's skin riblets produce counterintuitive friction reduction in water. Further exploration into how biological systems have developed surface articulation in similar ways uncovered two primary targets. Most notably the research of Haecheon Choi (2009)[4] from the Center for Turbulence and Flow Control Research at the Bio-Mimetic Engineering Lab revealed two species that inspired further exploration in relation to buildings — the saguaro cactus and sailfish.

PROBLEM

The research presented here was instigated by questions raised at balcony scale across a building surface and then coupled with the bio-mimetic studies at a smaller relative scale to the overall object. This led to questions surrounding surface articulations in relation to building performance other than load shedding and to investigate more closely a finer scale of articulation at the building surface. Based initially on the research by Choi that suggests the saguaro cactus uses surface manipulations to reduce the effects of convective thermal transfer, the question became can a building do the same — reduce convective heat loss or gain simply through creating surface articulation? Of course, whereas manufacturing

Figure 1: Biological Case Studies for developing turbulence at surface. Left side the saguaro cactus and CFD of the cross-section turbulence. Right side a sailfish and CFD of surface turbulence.

and aesthetic concerns for the cactus are evolutionary these become added dimensions of investigation for building cladding. A final constraint for the experiment would be the economics of the system. To achieve installation the outcome would need to be inexpensive materially while considering costs for labor and additional infrastructure; structure, fasteners, etc.

When taken together the material challenge would be to produce a lightweight yet dimensionally thickened surface while the aesthetic challenge would be to create continuity and variation across that same surface. The performance challenge is to, like the saguaro cactus, produce a surface that produces turbulence at the surface to create a layer of stagnant air that would reduce the exchange of heat energy to convection (e.g. Figure 1).

DESIGN AND PRODUCTION

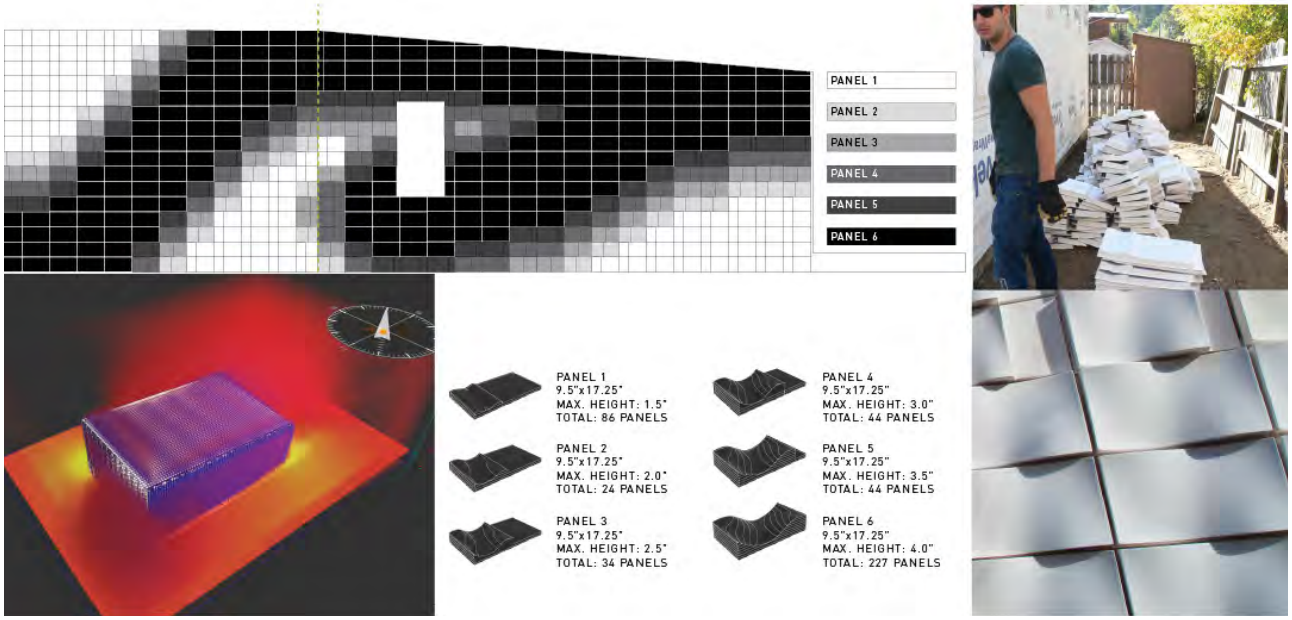
The execution of this research was developed in two parallel tracks. One track being the study of the craft of the product; computational design to manufacturing, development of connections for installation, assembly details for water shedding, and pattern making for variation with minimal units. The next track being to study the ability of the surface to create turbulence along the surface developing the desired performance in a design that meets the aesthetic requirement. These two tracks would periodically unite to produce prototypes for testing.

Phase 1 - Cladding - Phase one began with a group of independent study exercises assigned to a small group of students to study producing a lightweight dimensional cladding system. Born out of project commission of the architecture firm E/Ye Design and brought into the academy as research, the emphasis for this first study was given to designing the physical details needed to develop a method for cladding. This initial prototype was limited to a 9” x 18” dimension based on available manufacturing equipment found in the academic. Glass Fiber Reinforced Plastic was chosen as the initial material due to its strength to weight ratio and its ability to easily be cast into multiple shapes. Working with a composite manufacturing company, Windsor Fiberglass, these dimensional limitations were translated into numbers of molds that would be donated to facilitate production and testing. This partnership resulted in the production of a cladding system that had six unique unit types to generate desired performance and visual effects. The students consulted with the manufacturers to develop a tabbing system that would be built into the molded part and shingle to develop a positive drainage plane across the surface (e.g. Figure 2).

The geometric articulation for this cladding system drew inspiration from both the Saguaro Cactus and from the phenomena of drifting snow as this first prototype would be installed on a small building in a snowy climate. Low resolution CFD simulations done in Autodesk’s Vasari were used to verify that the iterations of the geometry were indeed producing turbulence at the surface as shown in the lower left of figure 2.

After completing phase 1, it was concluded that the panel size of 9” x 18” was too small to be economically viable as a deployable product. Additionally, this iteration did not account for corner detailing and therefor was not a complete cladding system. The lightweight panel and factory production did result in reduced installation time and labor costs as only 2 persons were needed for installation with no field cutting and zero on-site waste.

Phase 2 - Patterns and Edges -Based on the successes and failures of phase one the architecture firm and manufacturing company determined it was worthwhile to put more research into the product. Without having a commission for the another installation, phase two of the research was undertaken within a seminar course sponsored by the composite manufacturing company. Sponsorship, included support to produce four commercial grade molds and produce enough parts for a small installation within the School of Architecture



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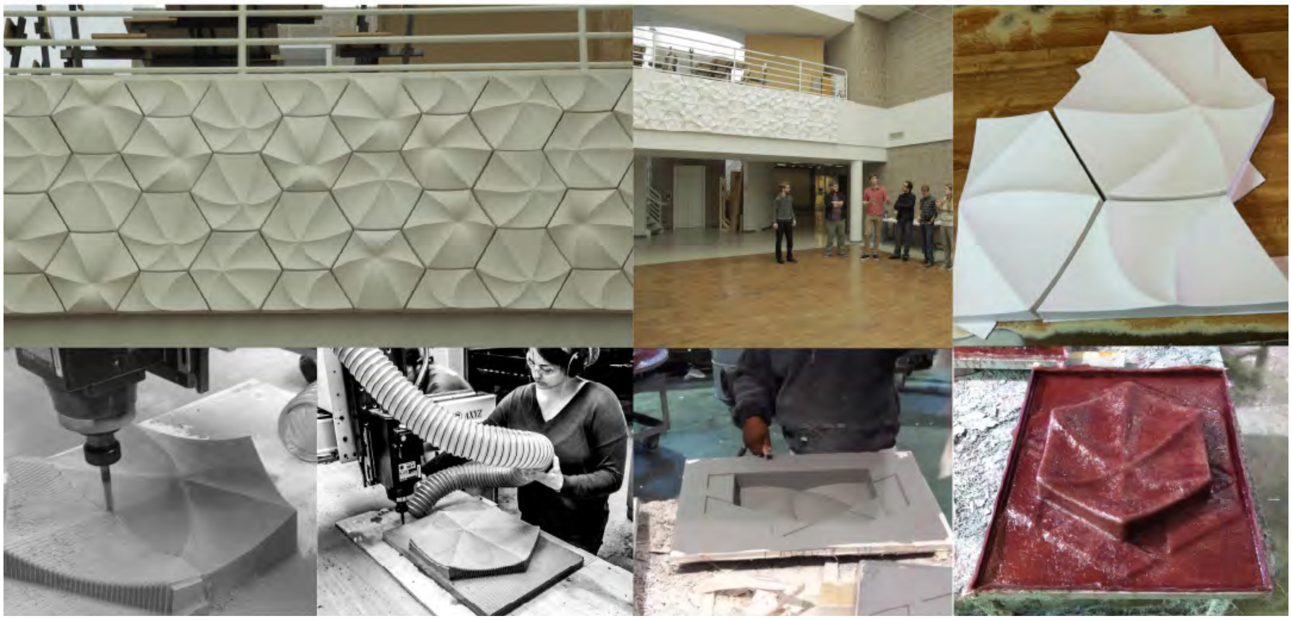
Salon. The focus here was to generate as much variation as possible and develop finished edges for the aggregated system with the allowed four molds. The students developed and tested several pattern studies until it was determined that a hexagon grid would be used. Two molds would be used for edge condition and two for the field. If the tabbing and connections were designed properly the two field units within the grid would each have six degrees of rotation giving the system an extreme amount of variation. Again working with the manufacturer the students produced the four patterns (positive plugs used to create molds) using the schools advanced CNC and manufacturing equipment designed with guidance in the form of constraints given by the manufacturer. Constraints such as draft angles for removing parts from molds, minimum radius of corners to ensure no cracking or fatiguing and level of finish for the final part would all be included by the students directly into their computational models that then were used to drive the CNC equipment to produce the patterns. The final installation was manufactured under the students direction, ordering proper numbers of all parts and providing labor for installation (e.g Figure 3).

Phase 3 - Corners and Scale - Phase three comes on the heals of phase 2 but this time with the support of another architecture firm, Liquid Design, commissioning the facade to be installed on a project of their design. Selected students from the previous phases were given internships to design a new system for the building facade installation. In collaboration with the architect and manufacturer it was determined that the larger the panel the more economic the product would be — with a limit being that it would be able to be carried by two crew members. However, as the mold increases in size the cost of manufacturing the mold increases dramatically. It was therefor determined that a single corner and single field part would be manufactured to reduce cost accosted with the mold production.

At this larger scale, a new design was needed. The inspiration for this project emerged from a return to the biological studies - in this case the sail fish (e.g. Figure 1) was chosen due to the more flowing graphic. The pattern generated on the surface of the sailfish was used as the inspiration to study a new articulation that would appear to move continuously along the length of the building while using only a single mold. While a sailfish is always oriented optimally to flow, a building will be confronted with any number of flow directions. Additionally, the corner research from phase 2 revealed that breaking up the corner vertically would relieve the generation of the large negative pressure build along the leading edge (e.g. Figure 4).

Figure 2: Phase 1 prototype installation. Bottom Left showing CFD simulation with blue turbulent layer generated along surface. Above the macro pattern of six tiles. Right installation.

3 

The results of phase three are a corner element 30" tall x 54" along each edge and field panel 30" x 144". Due to its size a new material matrix had to be developed. The resulting material is a glass fiber reinforced plastic with a rovicore© substrate to stiffen the part.

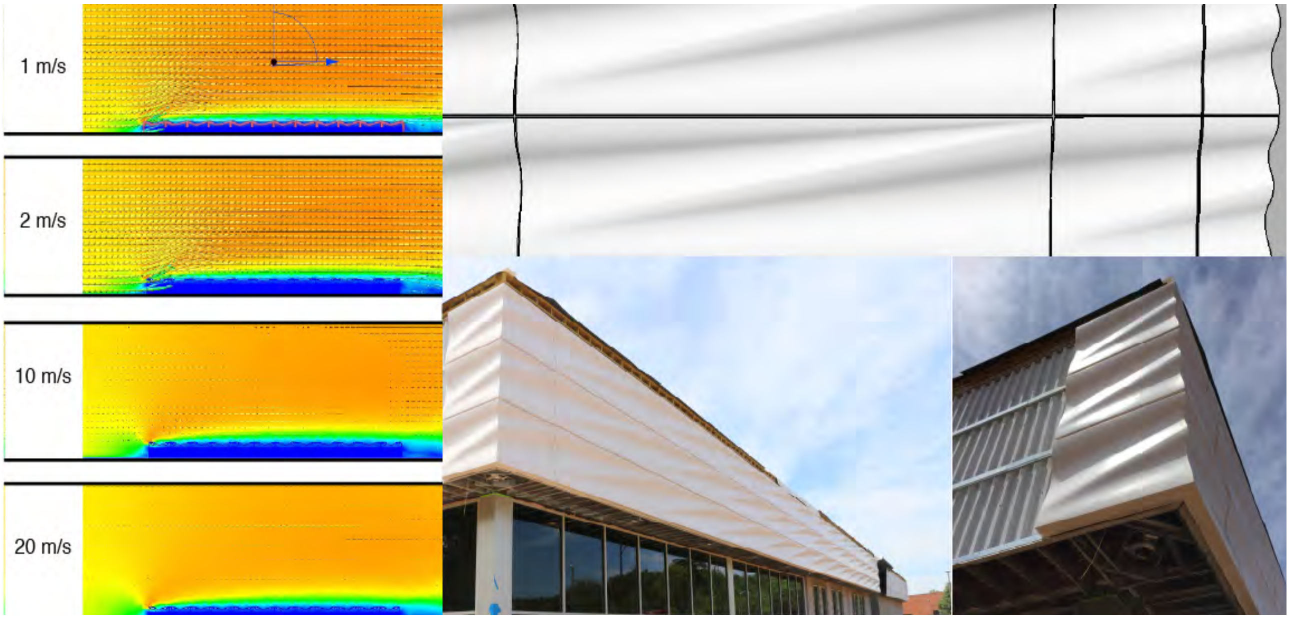
MANUFACTURING

In all three phases the students met with the manufacturers to work through the production process. Understanding the constraints of open mold hand layup for the first two phases provided great insight into issues of 'customized' mass production which according to the manufacturer are how they define part runs of less than 300. In working with the manufacturer the academic responsibility was to produce the patterns that would be used to generate the molds for the finish parts. The pattern held all final requirements including finish as the parts would be used directly from the mold. Without post-processing other than trimming all issues associated with production had to be built in to the pattern such as ensuring the part would properly release from the mold while maintaining acceptable visual tolerances. Phase three introduced a new technique for production called Light Resin Transfer Molding (LRTM). This technique uses a closed molding system were vacuum channels are built into the mold to draw resin into the mold. This technique allows for greater control over part consistency and ultimately a stiffer part.

All phases within the study essentially entailed the same three major steps. The first step was handled wholly within the academic environment and included several rounds of consulting with manufacturers to produce the patterns for mold production. Patterns were milled on a 3-axis router from either MDF or high density foam. The team would then prime and seal the pattern with a hardened primer and hand finished to desired level of smoothness. The manufacturer would then take the pattern and produce the master mold by spraying the pattern with a hardened tooling gel coat followed by a very thick resin and glass layup. Finally, the manufacturer would begin running parts through these molds (either hand layup or LRTM) and trim the edges of the parts to specified requirements.

Figure 3: Phase 2 sponsored coursework. Top: final installation, presentation and molded parts from factory. Bottom: Milling patterns and mold for parts.installation.

It was here that the academy had the most impact on the manufactures assumed methods for production. Typically, the bulk of the financials are invested in the production of very expensive patterns to produce master molds when producing even moderately complex geometry. By using computer controlled manufacturing processes to generate the patterns instead of traditional methods, several thousands of dollars were saved and very precise



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patterns were produced. There is some inherent risk as these patterns were destroyed in the mold making process but at a fraction of the cost of traditional pattern making the losses can easily be absorbed.

DISCUSSION AND CONCLUSION

Without a doubt the most successful part of this endeavor was working with a manufacturer to produce a finished, mass produced product that could be applied full scale to a building. In all three iterations the teams challenged some aspect of the manufacturing process to produce a more finished part than the previous iteration. This was only made possible by working closely with the manufacturer and architect to fully understand the constraints of their systems and how they could be translated into an architectural product. The success of this effort is demonstrated by the willingness of the Architects to engage the use of the product for their projects — convincing their clients that this technology and aesthetic would set them apart.

Turbulent Surfaces - While the initial computational fluid dynamic (CFD) simulations do indicate that a layer of turbulence is being generated by the geometric articulations verifying this in the field has proved difficult at full scale. This CFD testing of the cladding system confirms that the panels are environmentally activated through the interaction between the panel shape and the velocity of the wind —as airflows across the facade increase, the more turbulence the cladding geometry generates at the surface. This turbulence creates a thickening layer of 'stagnant' air along the building facade. The turbulent layer has an effect of adding an insulate airspace to buffer against the convective thermal transfer through the buildings facade. Additionally, this layer normalizes the pressure differences between interior and exterior when compared to a conventional flat facade. At lower air speeds the cladding allows the building to 'breath' as expected to avoid some issues associated with hermetically sealing a building. In this way the cladding acts more like a membrane allowing for a variety of exchanges, depending on climate and condition. Smaller scale models of the system will be needed to verify the development of turbulence at the skin in a wind tunnel. It is clear that if the turbulent layer is being generated at the surface of the building the heat exchange due to convection would be reduced — passively insulating the structure without hermetically sealing the entire building.

Figure 4: Phase 3 commissioned work. Left: CFD simulations of surface with corner. Top: Rendered model. Bottom: Building installation with new corner detail.installation.

Pattern Differentiation - There have been varying degrees of success with the aggregation of the pattern and generating variation with few unique parts. The first iteration relied on the most amount of unique parts but could be patterned to create an infinite amount of variation within the general aesthetic of that system. This version however, does not afford turning corners or elegantly terminating the run of parts. The second iteration of the research produced both incredible variation and allowed for the system to be terminated well. Parts were produced to turn corners as well though these were not incorporated into the final installation. However, performance as an exterior cladding system was compromised due to the modifications to the connectors that were developed to allow for the six degrees of rotation. The final iteration illustrated here in this paper does not afford nearly the variation in geometry of the previous studies but makes up for that in the two ways. One, the way the designed geometry produces a visualization that aggregates across the seam to blend the system into more of a whole — this gesture moves the eye in a different way than the gridded seams and maintains this visual play around the corner. Two, the subtle rolling of the geometry is interrupted with a crease to catch the sunlight in different ways creating visual variability through the day.

Cladding System - The efficiency of the system as a wall cladding system has continued to improve with each literation. Even at the largest scale, 36” x 144”, installation could be handled by a small crew of 3 without major heavy equipment. Phase 2 of the research proved to develop an incredible amount of variation with only 4 unit types but could not adequately shed water due to the necessary modifications made to the connections to allow for assembly. The final iteration proved a very efficient cladding unit with excellent environmental protection. Each unit covered 36 square feet of facade and could be installed at a very fast pace. The system shingles in the horizontal and laps in the vertical to positively drain water. Additional drainage channels are introduced within the vertical lap to prevent capillary creep behind the membrane.

At the moment, due to fire safety issues, the system can only be used for single story buildings less than 40 ft. However, with current research into resin compositions it will be possible to deploy lightweight systems made of Fiber Reinforced Plastics such as these on larger projects. Outside of the thermal benefits developed in this study through articulating the geometry, simply reducing the weight of a cladding system even a little will produce substantial savings by reducing building infrastructure to carry the facade. This not only reduces upfront costs but potentially embodied energy and total lifecycle cost for the building.

Future Considerations - In the end, working directly with a manufacturer for a specific installation was critical to the success of this research as imparting material expertise and production knowledge played a large part in the success of the project. Constraints driven by this relationship drove innovative solutions to achieve the aesthetic considerations for the project — namely producing visual differentiation without custom a price tag — while meeting performance goals. The partnership with the composites manufacturing company and the demands of practice have produced a secondary but important aspect of the system - the resultant solutions are extremely lightweight in comparison to typical claddings due to the material matrix. This means labor costs and installation time have been reduced dramatically which has afforded more capital investment into the design aspects of the system.

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Triakonta BB100: Dynamic Systemization Meets Big Bamboo

"Less is more." (Mies van der Rohe, New York Herald Tribune, June 28, 1959).

Less is core. (David Wharton, the-neighbourhood.com/thinking, Dec. 12, 2014)

"How much does your building weigh? (Buckminster Fuller, 1978)

"How much does your building impact? (Jack Elliott, 2015)

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INTRODUCTION

Bamboo has long been used as a vernacular building material in tropical regions all around the world. Methods of construction have typically involved ad hoc, inexact processes of in situ cutting, drilling, notching and lashing, relying on local building cultures and knowledge. However, in a globalizing economy, this traditional means of building has become associated with poverty and/or cultural nostalgia. Bamboo construction is not widely accepted as a viable, modern means to making buildings in tropical markets, despite its many environmental benefits. Bamboo is a rapidly renewable material that can grow in exhausted soils, phytoremediate brownfield sites, control erosion, and sequester carbon. Using bamboo reduces harvesting pressures on much slower-growing local forests. Additionally, not only are the bamboo fibers strong and light, but their configuration as a hollow tube is extremely efficient for structural applications. Some recent commercial attempts have been made to use bamboo for architectural structures but they are either prohibitively expensive because of the lack of standardization and labor-intensive techniques or the fibers are reconstituted into dimensional lumber, no longer recognizable as bamboo.

The Triakonta BB100 structural system was developed at Cornell University to overcome these problems. It is designed to offer a lower cost alternative to building with bamboo than with other bamboo building systems available in tropical markets. It is also designed to provide great formal variety using a very limited set of components, rather than customizing every component for each new project. This substantially reduces production costs. Finally, it is designed for reversibility, both in assembly as well as component construction. This allows for greater responsiveness and flexibility for changing functions or locations.

The Triakonta BB100 system responds to real building needs in tropical contexts, but is not intended for widespread use in mid-latitudes, both North and South. However, it does provide some important directives for contemporary practice in these non-tropical contexts. Whether using bamboo or not, lowering the embodied energy of buildings is becoming more important as operational energies of buildings drop. Designers must become more aware of the carbon footprint of the building materials they specify. They also must become more aware of the end of life issues associated with buildings. Typically, they are demolished, losing most of their material's potential for reuse. Designing for disassembly ensures that at its end-of-life, the building is not destroyed but is reconfigured or dismantled. Designing for reversibility ensures that all of the component materials can be separated for recycling or repurposing. Building can be reconsidered as a new way of storing materials.

BAMBOO BACKGROUND

The species of bamboo used for the Triakonta BB100 system is *Guadua angustofolia*, the world's largest bamboo, native to South America and widely cultivated in Colombia. This rapid-growth building material has been used for centuries but since European settlement has come to be regarded as a substandard building material because it is a cheap, accessible material commonly used for improvised housing[1]. However, recent uses of bamboo in high-end homes and high profile projects have brought renewed attention to the beauty, strength and elegance of this humble building material. The most emblematic example was the Zeri pavilion made of guadua, designed by Colombian architect Simón Velez for the 2000 Hannover Expo[2].It has also been used increasingly in residential and commercial applications in Colombia. In 2010, guadua was included for the first time in the Colombian building codes, allowing for its use in residential one and two story buildings, an important step for increasing the credibility of Guadua as a building material[3].

Bamboo is a grass, and this particular species grows up to 8 inches a day and reaches its full height in six months. The culm itself takes 4 to 5 years to mature into a structurally sound element. It can grow to a height of 100 feet, with a diameter up to 8 inches. Its compression strength fluctuates between 5000 Psi and to over 7000 Psi[4], comparable to white oak. However, unlike trees, when the bamboo culm is harvested, it does not kill the plant. The well-established root system will send up another stalk in the next growing season to repeat the harvesting cycle.

The best time to cut bamboo is before sunrise just after the dry season has started. This time and season ensure the minimum amounts of carbohydrates and moisture are present in the stalks[5]. After being cut close to the ground, the stalks are left standing intact for four weeks, with the cut end placed on a stone to allow the parenchyma cells to continue to digest any reserves of starch in the plant. This process is known as post-harvest transpiration and it is done primarily done to improve the culm's resistance to insects, but the dryer, lighter stalks are easier to transport and will finish drying faster.

The culms are then transported to a mill, where they are given a chemical treatment to preserve and protect the bamboo. The treatments depend on their uses: exterior applications use fixing preservatives such as ACQ while interior applications typically use boron salts. These treatments are done through a leaching process, where the culms are drilled longitudinally and wholly submersed in treatment tanks for 3-4 weeks. After treatment, the culms are air-dried out of the sun, usually in horizontal stacks. The poles are rotated end for end every two weeks over the drying period. This takes 6-12 weeks but is a necessary step to prevent cracking of the stalks. Afterwards, the treated, dried culms are cut into 20-foot lengths and are sorted according to their two end diameter sizes. The largest pieces are 6"-7", ranging down to 2"-3".

THE TRIAKONTA BB100 SYSTEM

The Triakonta system is named after the rhombic triacontahedron that it uses as a structural node. Rather than use spheres that are custom-drilled for each application, a regular uniform polyhedron with flat faces was sought to provide a better bearing surface for the ends of the struts. Examples of polyhedral nodes from industry usually include Archimedian solids such as the truncated cubes, like the cuboctahedron, or the truncated octahedron.

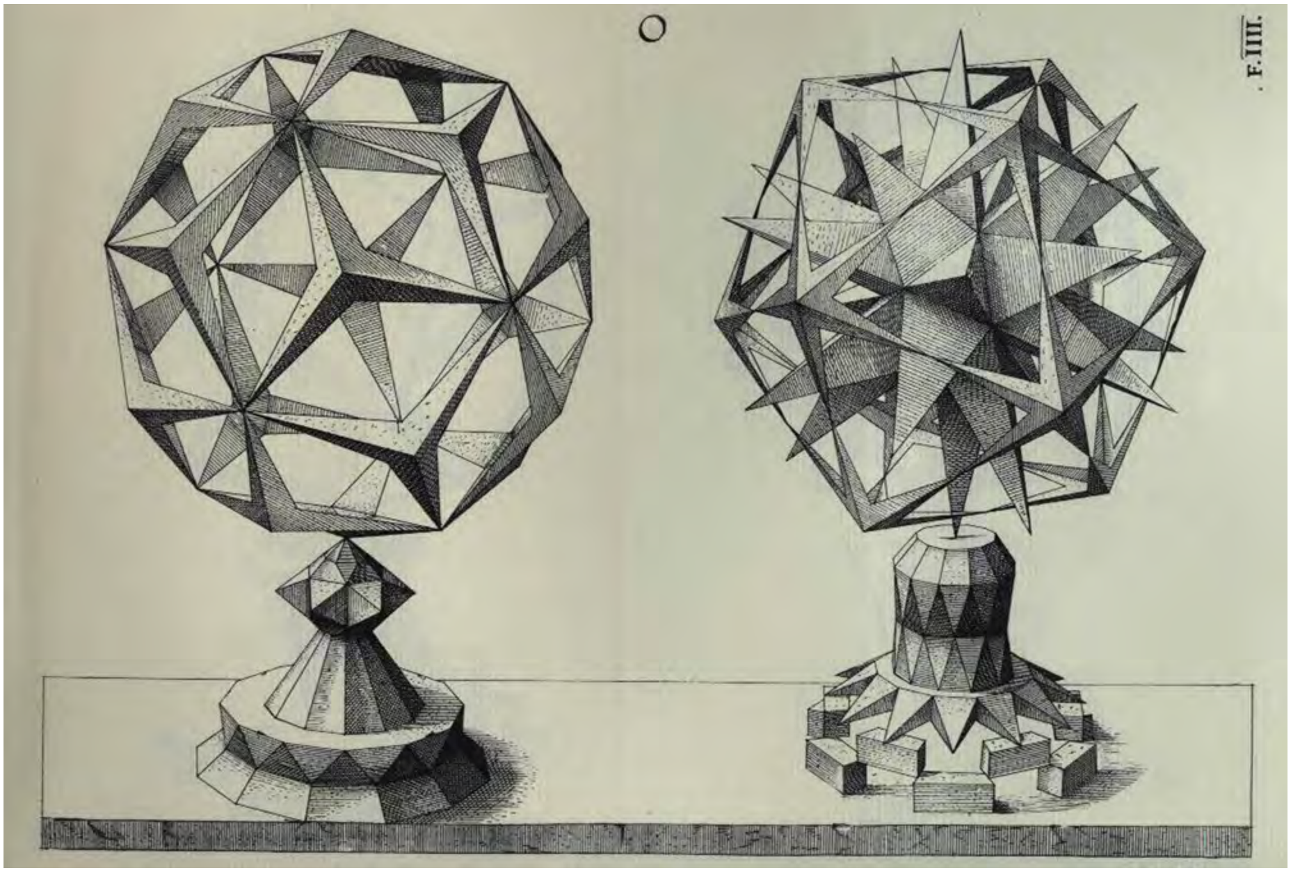

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Figure 1: Triacontahedron on the left, (Intaglio print: Jamnitzer, *Perspectiva Corporum Regularium*, Jamnitzer, 1568): Plate F IIII.

However, these have limited internal angular relationships. Instead, a 30-sided convex polyhedron known as a rhombic triacontahedron, was selected, hence the product name “Triakonta”. The “BB” refers to “bamboo” and the “100” refers to the metric measurement across the opposite flats of the node. This polyhedron was first discovered and depicted by Jamnitzer in 1568 (Fig. 1), although it is often attributed to Kepler, whose mathematical description appeared 43 years later. This shape allows for orthogonal structures with right angular relationships, as well as triangular, pentagonal, and hexagonal arrangements.

In addition to this geometric complexity, the Triakonta system is unique among geodesic structural systems for its use of Guadua culms for the struts of this geodesic system. Typical geodesic systems rely on metal tubing, precise and uniform but with little character. The Triakonta system exploits the hollow configuration and familiar look of the natural material while allowing for its irregularities of dimension and form within a standardized set of building components. The structures have a “natural” look but have very tight tolerances. These are shipped to the jobsite where they are placed in jigs to ensure they are cut to exact lengths and drilled in precise locations for the attachment of end anchors.

The anchors are made from 0.625” x 16” stainless steel bolts inserted through a hole drilled in one end of a two inch length of 0.25” - 2” x 6” aluminum rectangular hollow section (R.H.S.). The bolt is free to rotate and move along its axis. Perpendicular to the bolt on the other end of the R.H.S., the sidewalls are drilled to accommodate a 1.25” diameter by 6” aluminum pin, which fixes the assembly to the side walls of the bamboo. A concrete cone is placed over the bolt to allow a number of struts to converge on a single node without interference. These cones are made of Ultra-High Performance Concrete to provide the ductility and tensile strength necessary, cast in 3d-printed molds. A stainless steel dowel pin is force-fit into a tight tolerance hole that is located on the exposed end of the bolt. A broached

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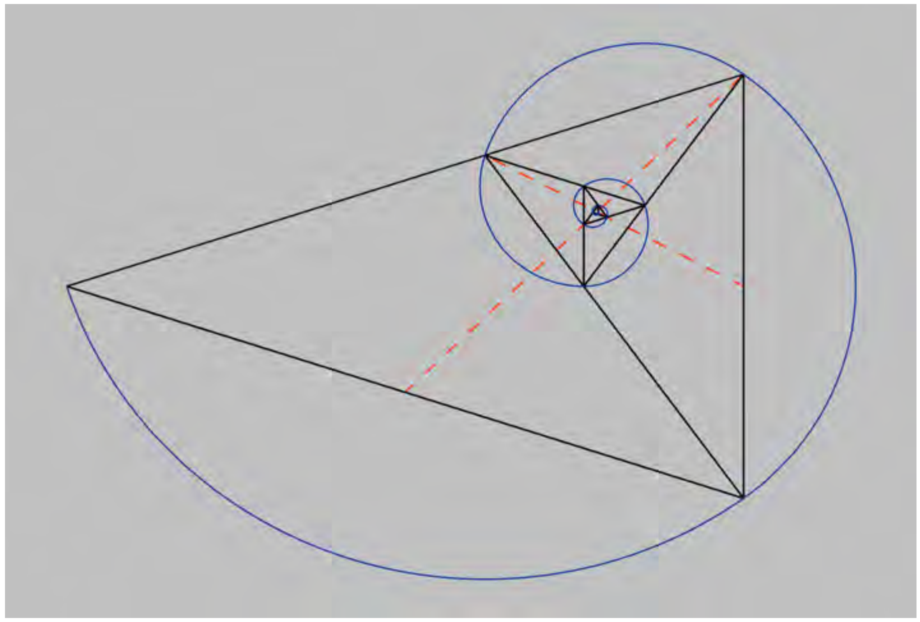

stainless steel collar fits over the bolt and engages with the pin. The collar is drilled on the outside to accommodate a pin wrench which is used to rotate the bolt in or out of the node. This single specialized tool is used for the entire assembly/disassembly process while rendering the structure tamper-proof.

Connecting the rhombic triacontahedral nodes automatically generate dynamic/golden/divine relations between the component lengths, as referenced in the title of this paper. The term ”dynamic” is used in the geometric sense as defined by Jay Hambidge in his book “The Elements of Dynamic Symmetry”[6] referring to uniform growth often found in nature. His use of the term ‘symmetry’ is understood as the Euclidian concept of commensurability. His principle of proportioning was derived from the study of Greek building and artifacts where “root rectangles” and their diagonals produced a system of geometric relations.

In the case of the Triakonta system, these relations are based on √5 rectangles, which imbed the Golden ratio. Connecting three rhombic triacontahedrons with straight line segments normal to their faces produces triangles that are either equilateral or isosceles. The isosceles are of two types: narrow or wide (Fig. 2). In either case, the lengths of the sides of the isosceles triangles are related to their bases by the Golden ratio or its inverse. Thus, the rhombic triacontahedron produces a three-dimensional system using only three different lengths: short, medium, and long, each greater than the preceding one by a factor of 1.618…. The result is great configurational variety with few standardized components. Additionally, the system is designed for disassembly, so that the building can be modified to accommodate changing conditions or at the end of life, can be completely dismantled and re-configured for a new site or set of conditions.

A working prototype of the Triakonta BB100 system is about to be erected this summer and field-tested in the Dominican Republic in the form of a simple gable structure (Fig. 3). It is triangulated on the outside to allow for a large free-space inside to serve as a classroom or meeting space at the Puntacana Ecological Foundation, a non-profit arm of the Puntacana Resorts and Club.

For the past 19 years, the mission of the Foundation has been to protect and restore the natural resources of the Punta Cana region and contribute to the sustainable development of the Dominican Republic. For the last four years, they have served as a local partner for

Figure 2: Golden triangles in Fibonacci spiral (Image: Wikimedia Commons)

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Figure 3: Triakonta BB 100 structure fully assembled, Cornell University, 2015 (Photo: Jack Elliott)

Cornell University's Triakonta research project. In addition to the system's inherent sustainability, its triangularity, low weight, and high strength make it suitable for this region's seismic activity and hurricane winds. If technically and culturally successful, the Triakonta system could form the basis of new local industry with vocational training for local contractors and even a new agro-forestry initiative sponsored by the Foundation. In this way, architecture could possibly play a role in reducing deforestation pressures while providing new safer, greener solutions to habitation in tropical and subtropical regions of the world. But what about the non-tropical places?

GATHERINGS FROM GUADUA: EMBODIED ENERGY

While this research is geared for projects in the developing world, the Big Bamboo project has some important suggestions for the developed world as well. One of the most important of these has to do with embodied energy, the amount of energy that is required to convert a raw material into a finished product delivered to the building site for its final disposal. As humankind starts to understand the impacts the built environment is having on the biophysical world, designers and architects need to re-think standard practices. On the issue of climate change, much work is being done on reducing the carbon footprint of buildings but mostly from an operations point of view. However, embodied energy is also an important factor for building impact, but is more difficult to quantify.

Certain researchers count the upstream energy consuming processes of a given product or building, while others consider the energy expended at every stage of the life cycle.[7] Despite these inconsistencies and lack of a universal framework to calculate embodied energy, the current consensus is expressed by Manesh Dixit, a prominent American scholar on building energy assessment, who states that current research has "found that embodied energy accounts for a significant proportion of total life cycle energy."[8] He cites two Australian studies that have demonstrated that embodied energy costs could be equivalent to a range of 15 to 50 years of operational energy costs[9] (Fig. 4). Since the average age of a commercial building in the U.S. is 41.7 years[10], if a building is a high performance building, more energy is embodied than consumed over its entire lifecycle. However, embodied energies of materials are just now being considered in green design protocols. The Living Building Challenge 3.0 in the "Materials" section under "Embodied Carbon Footprint", although not all energy

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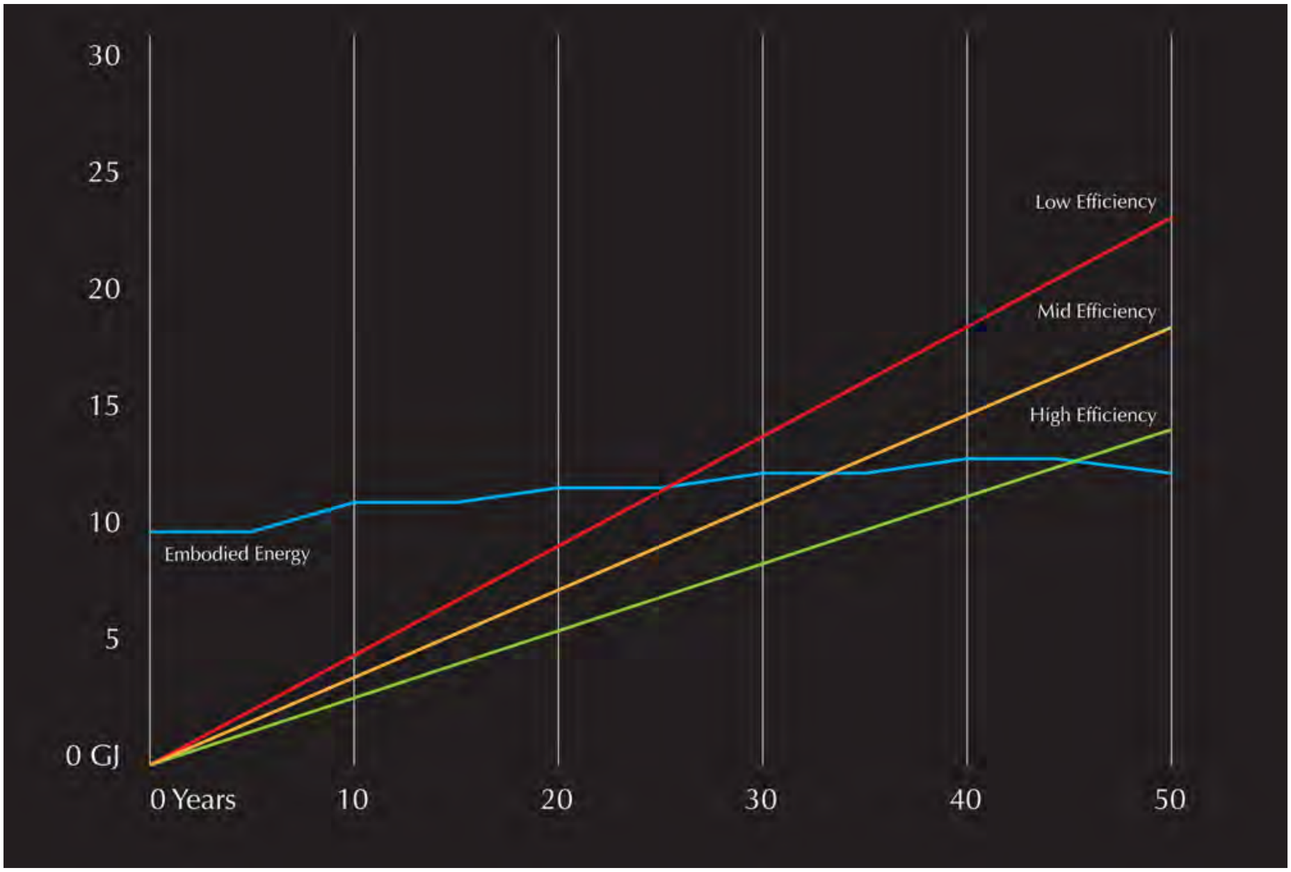

Figure 4: Cumulative Energies of a Building (Graph: Adams, Connor and Ochsendorf, MIT OpenCourseWare)

generates carbon. Renewable-energy-created cars may have a small carbon footprint but have large amounts of embodied energy. All energy is worth conserving, renewable or not. LEED v4 has a new credit called the "Building life-cycle impact reduction" but the term "embodied" is not included in the description.

This dynamic does not just apply to buildings. A recent article in Green Car Reports is entitled "As Gas Mileage Rises, Energy To Make Cars Gets More Important"[11]. Volkswagen completed a study in 2014 on its Golf 1.6 TDI where it found that the embodied energy of the car was 22% of its total carbon footprint over its lifetime, compared to 6% in 2000.

TEACHINGS FROM TRIAKONTA: DESIGN FOR DISASSEMBLY

Another important concept that is often overlooked in the design and construction of the built environment is the end-of-life impacts of the intervention. Buildings are "demolished", "destroyed", "wrecked" by wrecking balls, "bulldozed" by bulldozers where all of the potential for re-use of the materials is lost. Building demolition wastes make up almost 50% of U.S. construction and demolition waste totals, which were estimated to be 136 million tons in 1996[12]. Not only is this a massive amount of material, it requires even more material to be extracted to replace that which is lost in the built environment. All of the methods we use to resupply these lost materials have substantial carbon footprints embodied with them. This planet cannot continue to be an unlimited source as well as sink. We need a new plan.

Imagine a scenario where instead of "demolish" or "destroy", words such as "dismantle" or "deconstruct" or "disassemble" where used to describe the end-of-life of a building. What are the implications of this? This means that the building would not rely on irreversible processes in its fabrication. No curing, no setting, no drying. Only reversible processes would be used. Screwing, bolting, clipping, fitting. No wet processes, only dry. The building becomes a new way to store material, recyclable or otherwise.

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Figure 5: Werner Sobek, R128 House, Stuttgart, 2000 (Photo: Voyager)

As radical as this sounds, there is a long tradition of building in this way. This practice is millennia old, often associated with temporary structures as seen in the Mongolian yurt or the Blackfoot tipi. However, more permanent structures have utilized this practice such as Paxton's Crystal Palace or more recently, Fuller's American pavilion at the 1967 World's Expo or Sobek's R128 House (Figure 5). The design for re-use and disassembly allows for nimble responses to changing conditions for its users, whether they are hunter/gatherers or millennials. The rapidly changing contemporary context is placing new demands on buildings that require properties of responsiveness and capacity for change while conserving resources. Designing for disassembly (DfD) allows buildings to meet these demands but these new approaches have new social, cultural, and environmental dimensions that the Triakonta system is meant to investigate.

The Triakonta system was designed with these ideas in mind. Not only does it incorporate the low-embodied energy of bamboo into a structure, it offers a modular, reusable structural framing system that is designed to weigh less, sequester carbon, disassemble, and generate exciting new geometries to work with. As the needs of the building change, the building can change without being demolished. At the end-of-life, the metal components can be reused and the natural components can be composted or pyrolized into a soil amendment or a source of cooking fuel. No composites to disentangle, no toxins to dispose of, the materials flows into both the technical and the natural metabolisms that will have to be set up to coexist for us to survive, let alone prosper in the decades to come.

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Computation and Clay: Evolving Fabrication and Performance Strategies for Ceramics in Architecture

Throughout civilization, fired clay has taken on various roles, ranging from utilitarian objects to decorative art. In architecture, fired clay, as a building material, demonstrates a wide range of uses. Typically used as a tiling system, ceramics have provided a means of waterproofing buildings, protecting structures from fires, and as an aesthetic device for decorating surfaces. This is true of historical and contemporary buildings, in both Eastern and Western cultures. Ceramics have a long standing role as a ubiquitous building material and its production has evolved throughout the history of architecture, from manual, to industrial, and now digital processes.

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The use of ceramic tiles in the built environment is vast, ranging from mass produced and assembled processes, to highly skilled and customized modes of craft. This paper presents a series of research projects, collectively titled Computation and Clay, that examine new possibilities for ceramics in architecture through the use of slip-casting, computation, and digital tooling, merging traditional and contemporary methods of making.

COMPUTATIONAL DESIGN AND PATTERNING

The *Computation and Clay* projects developed from a series of advanced, research-based architectural design courses, titled *Digital Craft*, which were developed and taught at Carnegie Mellon University and Louisiana State University. These seminar courses focused on the subjects of ornament and craft through the exploration of computationally generated patterns, digital fabrication processes, and casting techniques for phase-change materials (liquid to solid). 'Acuity' patterns, as described in Patricia Rodeman's "Psychology and Perceptions of Patterns in Architecture", were studied as a means of producing psychological and/or physiological affects by creating illusions of movement through the use of high contrasting and regimented geometries.[1] Algorithmic design processes were used to generate patterns and speculate on their effects.

Digital tooling strategies utilizing CNC-milling processes were explored to fabricate the intricate and complex geometries that resulted through the computationally designed patterns. Through the modification of machining variables, such as material selection, cutting speed, and bit sizes, the CNC milling machine was used to explore the crafting of surface effects in contemporary architecture.[2] Molds were made from the digitally fabricated 'master' parts, and used to cast phase change materials, that transformed from liquid to solid, such as resin, concrete, and ceramic slip. Casting out of various materials was encouraged as a method for discovering unanticipated qualities, attributes, and expressions of the material. The molds also provided a means for casting multiple identical components that could be assembled to form larger surfaces and fields.

This process established a heuristic approach to learning by providing students with a basic workflow for design and fabrication, while allowing them to discover new opportunities for materials and their potentials for effects and performance. In these studies and experiments, the slip-casting technique and ceramic material stood out from the others in that, the cast part contains a hollow cavity, creating a void space that makes it light in weight. The material also undergoes a transformation when firing, in form and scale, and seems to provide more opportunities for surface finishing. These observations lead to more in depth research into the historical use of ceramics in architectural design.

1

HISTORICAL EXAMPLES OF CERAMICS IN ARCHITECTURAL DESIGN

The use of ceramics has a long history dating back thousands of years. Etymologically, the term “ceramic” stems from the Greek term “keramos” meaning “the potter’s clay”, and is derived from an older Sanskrit root, meaning “to burn”.[3] These definitions describe the material, but also highlight the importance of the process. Clay is a plastic, malleable material which, when fired, undergoes a transformation and hardens. These drastic changes within the material provide both high levels of flexibility, in sculpting forms and shapes, as well as durability, against the effects of weathering. The permanent aspect of ceramics has served to date archeological digs and has helped to preserve information which may have otherwise been lost. The earliest examples of ceramics include utilitarian objects in the form of pottery, made from clay, densified during the sintering process. Over time, decorative patterns and motifs were applied to utilitarian objects by imprinting the clay, or coloring the

Figure 1: *Digital Craft* student work

clay through glazing techniques, prior to firing. This combination of utility and decoration can be traced back to the earliest known examples of ceramics in architectural design.

In Mesopotamia, adobe bricks made from the river mud along the Tigris and Euphrates were used as the main method of building. In the Sumerian city of Uruk (3600-3200 BC), nail shaped ceramic cones were pushed into the outer surface of the adobe walls. This functioned to protect the walls from environmental and weathering factors such as wind and rain. The cone tiles, painted red, white, and black, were geometrically arranged, and served as a decorative pattern.[4] In the trabeated systems of Ancient Greek architecture, terra cotta tiles were placed on the wooden rafters of sloped roofs in order to protect the structure from rain. Three types of roof tiles systems were developed, each system comprised of various convex and flat tile arrangements. A special tile, the antefix, was placed on the edges of the roof and served as a decorative element used to mask the roof tile joints. The Ancient Roman hypocaust system, was developed to heat bath houses and other buildings. In this system, the floor level was raised, so that warm air from a furnace below could heat the floor. The 'tibuli' tile was a hollow, rectangular, boxed shaped tile that formed walls. The hollow portion of the tile allowed warm air to pass through the walls, and functioned to ventilate smoke out through the roof while radiating heat back into the interior space. The interior surfaces of the tibuli tiles were decorated with reliefs and patterns to enhance the aesthetic experience of the space.

There are countless examples of the use of ceramics in historical and contemporary architecture found throughout the world, and throughout various time periods. This includes the intricate, colorful, mosaic patterns found in Islamic architecture, the sculptural figures and shapes that form the roofs of Asian temples, and modern infrastructural projects that make up our built environment. These and many other examples of ceramics in architecture demonstrate the use of tiling systems that perform specific functions while simultaneously serving to decorate forms and spaces.

2

Figure 2: Ceramics in Architecture

CERAMICS CATEGORIES AND CURRENT MANUFACTURING METHODS

The three primary categories of ceramics include earthenware, stoneware, and porcelain. These categories are primarily based on the fired density and porosity of the works. During firing sintering takes place, fusing particles at a fast rate and leading to vitrification. Other differences include workability and color. Earthenware is a low fired clay that is non-vitrified, and therefore, not impervious to water unless glazed. Stoneware is vitrified at a particular temperature. Porcelain is vitrified, non-porous and white and glassy in appearance. Additionally, porcelain can exhibit translucent qualities if the surfaces are thin.[5] Three common methods for forming and shaping clay bodies include hand building, machining, and slip casting. Hand building methods include 'throwing' and 'coiling'. In these techniques, which have been used for centuries, clay bodies are shaped by sculpting the clay by hand. In throwing, the clay is shaped while it is rotating on a wheel, and in coiling, the clay is shaped by stacking rolled, coiled strips of clay. Craftsmanship is the result of the maker's knowledge and workability of the material, where the final form is not completely predetermined, but depends on his or her judgement, dexterity, and care while working.[6] In hand crafted objects, variation is easy to achieve, and subtle differences occur between copies. Typical industrial manufacturing techniques for ceramics include 'jiggering' and 'extruding'. Jiggering is a mechanized version of wheel throwing, in which the clay body is pressed or stamped by a tool into a mold. Extruding is a mechanized process in which the clay body is pushed through a die of the desired profile or section. Mechanized processes are used to mass produce multiple identical copies. This process removes traditional notions of craft, where the final forms are predetermined and the machines that produce them are calibrated to maximize speed and efficiency. Clay bodies can also be formed by 'slip-casting'. This technique requires a workability by hand but allows for the production of multiple copies. Slip-casting also allows for the production of complex forms and shapes that are difficult to achieve by hand making or industrial processes. In slip casting, a plaster mold is made of the desired form or object. A clay body mixed with water, known as 'slip', is poured into the plaster mold. The plaster mold absorbs water from the clay body through capillary action, drying the clay body that is in contact with the plaster mold. This results in a thickened shell, (the thickness is variable depending on the amount of time that the slip is in the mold), which can be de-molded when the desired thickness is achieved. The process can be repeated to produce multiple parts.

All of these methods yield different possibilities for shaping and forming clay bodies, which remain malleable and plastic until fired. The firing process, typically in a kiln, hardens the clay. The resulting ceramic material can be finished with various types of glazes, which adhere to the ceramic in a second firing, to produce different surface qualities, such as color and reflectance. Glazes also seal and protect the ceramic, and make it impervious to liquids. Within the ceramic manufacturing stages of forming, firing, and glazing, opportunities exist to create variability between copies, where 'identification is based on visual resemblance', and exact replicas between copies, where 'identification is based on visual identicality'.[7] Digital processes allow fabricated parts to be quickly modified by changing variables within computational models or digital fabrication machinery. Current technologies provide opportunities for architects and designers to fabricate geometrically complex forms and systems through the use of computational design processes and digital fabrication tools that extend the potentials for mass customization. The plasticity of clay bodies make them an ideal material for shaping complex forms and intricate details.

COMPUTATION AND CLAY

The *Computation and Clay* research consists of a series of projects that explore the potentials for evolving fabrication and performance strategies for ceramics in architecture through the implementation of computational processes and digital fabrication tools.

Similar to the merging of utility and decoration in the historical ceramic precedents, these experiments attempt to merge contemporary ornamental qualities of performance and effects. The studies explore computational patterning and a specific digital fabrication technology; 3D printing, CNC milling, and robotic fabrication.

The first project, titled, the *Specimen Series*, is the result of a collaboration with Justine Holzman of 7B7D. In this project, 3D Printing technologies and computational design tools were used to design a series of ceramic vessels. The forms of the vessels were parametric modeled, allowing for a 'family of forms' to be quickly produced with the modification of a few key variables. An algorithmically designed pattern was applied to the surfaces of the forms in the digital model, producing an intricate, articulated three dimensional surface for the vessel. The pattern produced a textured, field of concave and convex geometries which for gripping the vase, while aesthetically providing a sinuous and undulating surface effect. The digital models were exported and 3D printed out of ABS plastic. A five part plaster mold was produced from the plastic print and served to slip cast multiple components out of porcelain. The slip casting technique allowed the multiple copies of the vessels to remain similar in scale and form. Once fired, various glazing finishes could be applied to each vessel to produce uniqueness, and differences in the finished surface color and reflectance qualities. The project, and the process of making the vessels, yielded unexpected and emergent qualities which were further explored by experimenting with the material and craft.

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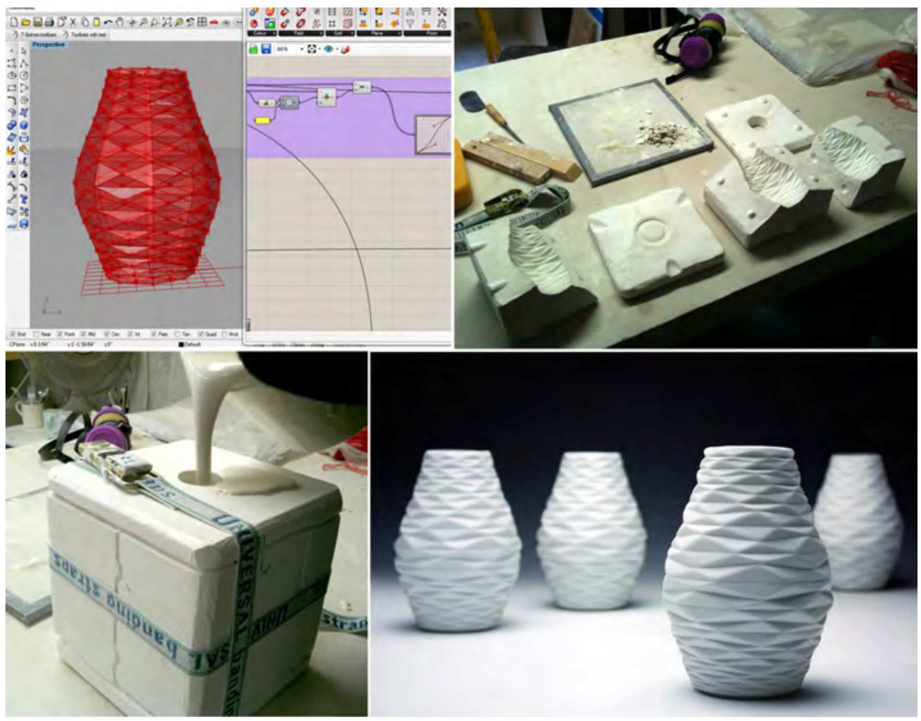
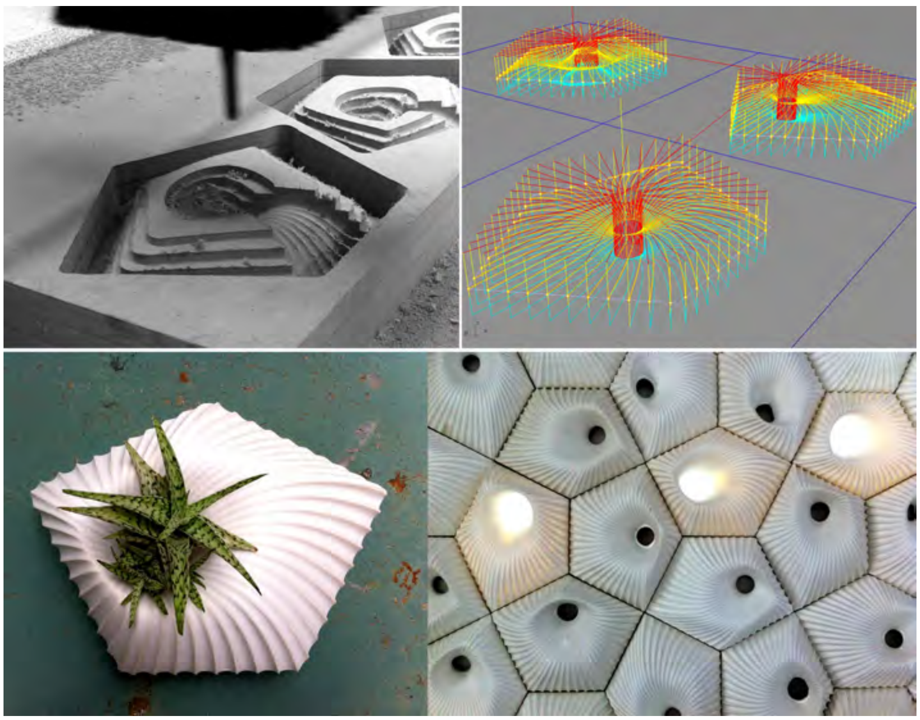


Figure 3: *Specimen Series* Project

The second project, titled *Cairo Bloom*, is the result of a collaboration with Seth Payne. The project explores the potential to create a three dimensional tiling system, based on the Cairo Tessellation, that achieves variation within a field through the use of a components with subtle differences. In this study, an algorithmic pattern of curves, within the boundaries of an irregular pentagon, was produced to generate the tooling paths for a CNC milling machine. The variables included the number of divisions, the scale of the aperture in the tile, the displacement of the aperture from the center, rotation of the curves, and the depth of the tile. Rather than digitally modeling a final form, and fabricating an exact replica of the model, this study sought to yield unanticipated and emergent qualities in the surface geometry through the fabrication process. Three components were CNC milled and used to create three plaster molds. The two-part molds were used to slip cast over 30 components that can be arranged to form a larger assembly. In this prototype for a wall mounted tiling system, the overall effect of the pattern creates a field of apertures and sinuous curves that imply motion. The aperture in each tile provides an opening into the hollow, void space of the ceramic tile, providing opportunities for various functions. For example, the void space can be used to hold soil and vegetation, to produce a 'green' wall that insulates and increases R-value. In this case, the tooling marks of the surface pattern creates 'channels' which can function to collect rain water and divert water to the plants. In another example, the void space was used to place individual lights. This produced a wall system that provides indirect lighting, achieved by placing LED lights within the cavities of tiles. The lighting pattern was designed to randomly illuminate various tiles, with gradual increases and decreases in brightness controlled through a microcontroller and code. The translucent quality of the porcelain, which is unique to other clay bodies, is exploited to produce a glowing, or blushing, effect.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The third project, titled *Rob-Plasticity*, was made possible with the expertise of Ezra Ardolino, founder of Timbur LLC., digital fabrication specialists servicing Brooklyn, New York City, and the Tri State area. This study, looks into the possibility of manipulating clay through robotic fabrication techniques. A block of earthenware clay was pressed and sculpted through the use of a square shaped wooden peg, attached to the arm of an ABB industrial robot. The project juxtaposes lo-tech and high-tech tools to test the ability to form and shape the plastic nature of the material. Computational patterning techniques were used to create a field of vectors that control the movement and position the robotic arm in space. The project seeks emergent patterns and textures by designing nuances in the motion of the robotic arm. The fabrication software provides opportunities to preview this motion, however, the resulting form and surface articulations yielded emergent qualities, as the behavior of the clay under stresses is difficult to predict or simulate through computation or modeling methods. The resulting pattern varies across the surface and produces a three dimensional texture. In this process, clay can be reshaped to run various tests and iterations, and

Figure 4: *Cairo Bloom* project

promises reduced amounts of wasted material while maximizing variability. This project is a work-in-progress which opens up exciting possibilities for the integration of robotic fabrication techniques as a means of producing new paradigms in the design of ceramic components and assemblies.

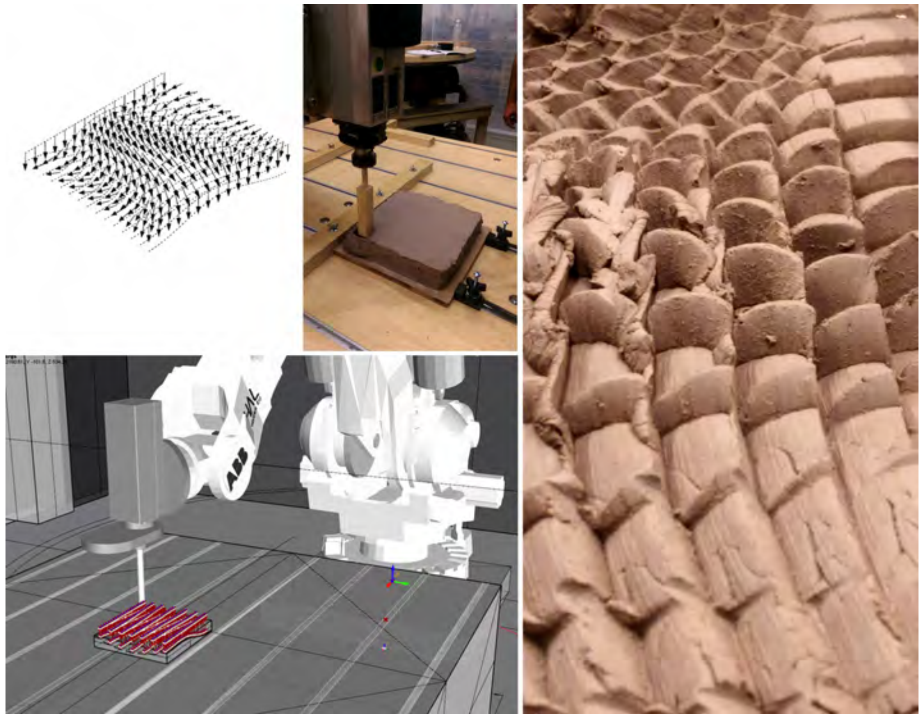

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Figure 5: *Rob-Plasticity* project

FUTURE POTENTIALS

The Computation and Clay research seeks to expand on the design and fabrication possibilities of architectural ceramics through the use of digital technologies. Algorithmic design processes provide opportunities to generate forms, shapes, and patterns that are geometrically complex and visually compelling. 3D printing, CNC milling, and robotic fabrication tools offer new possibilities for forming clay bodies into complex forms and geometries. In recent years, computational design strategies coupled with digital fabrication processes have reinvigorated the discourse of ornament in architectural design. Ceramics have contributed to architectural ornament by combining utility and decoration, performance and effect. Their durability, resistance to weathering, and aesthetic qualities, distinguish ceramics as a building material that has maintained a long standing role in architectural design. This role continues to evolve today and has emerged as a design trend that seeks to merge traditional materials and new technologies.

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Flex.Molds

Flex.Molds explores the potential of using flexible plastic in conjunction with standard 3D printing techniques to fabricate 3D printed flexible molds for casting concrete.

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INTRODUCTION

New 3D printing materials are currently being developed and released at a rapid pace, including flexible plastic filament that was recently introduced to the desktop 3D printing market. Flex.Molds explores the potential of using this material in conjunction with standard 3D printing techniques to improve the conventional fabrication process of precast concrete. It poses the question: can 3D printing formwork for concrete alleviate some of the problems associated with traditional casting by reducing fabrication steps and increasing geometric flexibility?

The initial research for Flex.Molds was carried out during an elective offered to undergraduate and graduate students at Kent State University, which subsequently led to design development, data collection and the development of guidelines for architects and fabricators who are interested in exploring this new technique. This paper describes the background research, current state of digitally fabricated molds, 3D printing materials, fabrication and casting processes, typical workflow from design to fabrication, design limitations and opportunities, and conclusions.

BACKGROUND: FLEXIBLE MOLDS

In the precast industry, there is a subset of companies that manufacture flexible molds or form liners for architectural applications, such as precast walls. One of the original techniques to create one of these molds is to cast an actual object, such as a brick, using a flexible polymer, such as urethane or rubber. There are now several additional techniques that have been introduced into the market to achieve the same result. They include using a CNC milling machine to mill out the positive of a mold and then casting it with a flexible polymer silicon (Bell 2012), or using a vacuum forming machine, which is very time efficient, to form plastic.

PRECEDENT: COMPLEX FORMWORK

The fabrication of molds for complex geometries is time and material intensive, and therefore steps are taken to control costs, such as maximizing the number of castings per mold (Clark Pacific 2000) or reducing the number of unique molds produced. Unfortunately these efficiencies can lead to the loss of design freedom. One contemporary project that highlights this issue is the concrete façade of Perot Museum of Nature and Science in Dallas, Texas that was designed by Morphosis Architects (Stephens 2013). To create the desired look for the façade, the architects used a set of modularized wax molds for the casting process. Originally, the unique molds were intended to be CNC milled out of wax and then cast out of concrete, however the number of variations was reduced down to 20 to optimize the fabrication process (Doscher 2011).

BACKGROUND: 3D PRINTING AND CONCRETE

Currently, several architects and engineers (Khoshnevis 2006; Buswell 2006) are focused on 3D printing large-scale concrete structures for architectural applications. These projects use a FDM (fused deposition modeling) technique to directly print with concrete-based materials. Large scale prototypes have been realized, however the technique has not yet resulted in a permanent structure. Flex.Molds investigates a different approach to utilizing 3D printing in architecture. Rather than directly printing building components in concrete, which has its own set of opportunities and limitations, this research explores if instead, digital fabrication can improve existing processes in building construction. Flexible formwork can be 3D printed and used to cast concrete with traditional methods, which could shorten the process of prefabricating concrete, while still relying on tested, industry standard processes.

BACKGROUND: 3D PRINTING MOLDS

There are several other projects that are being developed that showcase how 3D printing has an opportunity to offer new design possibilities for concrete casting. For example, the FreeFab project being developed by Laing O'Rourke Construction (Gardiner 2014) is utilizing a large scale 3D printed wax formwork that can be combined with CNC milling, while UCL Bartlett's Clay Robotics project utilizes unfired clay as a temporary mold for concrete (Sun, Kelvin, Wong 2014). These materials offer a unique opportunity to reuse the material from one mold to the next, but both lack the ability to create high resolution or detailed molds, due to the scale of the printing process. The molds themselves also cannot be cast a second time. While PLA flexible plastic is not a natural material, it does offer advantages that increase the accuracy and efficiency of 3D printing molds.

FABRICATION PROCESS

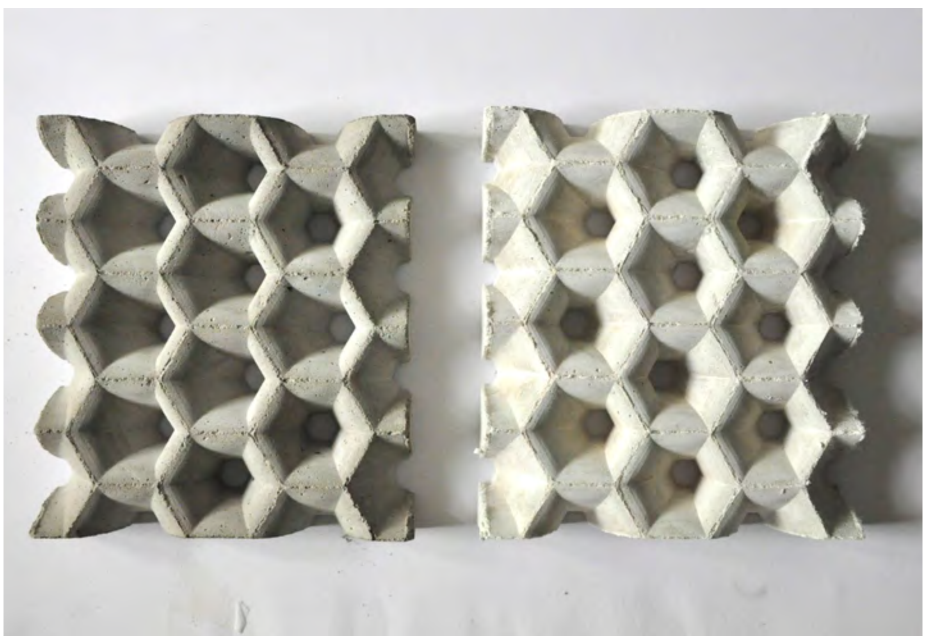
The Flex.Molds prototypes were developed in a single parametric definition that combined the design and fabrication parameters, allowing for the quick development of design iterations. The mold geometry was developed within Rhino's parametric scripting language, Grasshopper®. The initial step of the Grasshopper® definition defines the overall form of the application (e.g. wall panel) through the input of the design parameters of the desired structure. When using a desktop 3D printer, a slicing program is then used to simulate the movement of the printer and generate the tool path code. These simulations are necessary to identify any possible errors prior to fabrication, such as avoiding severe overhangs from one layer to another that can create imperfections in the mold.

Once the design is finalized, the flexible formwork is 3D printed. Research has been carried out using both small and large FDM style plastic extrusion system 3D printers. The project began on a small scale printer, which allowed for the quick identification of the opportunities and limitations of the material and fabrication system. At a larger scale, a commercially available, large desktop 3D printer was used, as well as a 6-axis robot arm. The robot arm had a customized plastic extrusion head end effector attached, which was used to prototype full scale molds up to 6 feet in diameter. Since the extrusion nozzle on the robot arm is larger than both desktop 3D printers, prototypes can be printed in much thicker layers, reducing the overall print time.

Once the print is complete, a release agent is applied to the mold and then the casting material is mixed, placed, and left to cure in the mold. Once the concrete is set, the flexible mold is simply removed and ready for another casting.

MATERIALS: 3D PRINTING

New 3D printing materials for FDM style printers are currently being developed and released at a rapid pace. Flexible plastic filament was recently introduced to the desktop 3D printing market and this project has been exploring its potential in creating flexible molds for concrete. The advantage of this material over standard rigid plastic filament is that a single formwork can be recast multiple times with no damage to the mold itself. Flexible molds hold their form during the casting process, but then allow the concrete to be easily released. It is important to note that while the material is quite flexible, it is not elastic, so it is not possible to stretch and use it in the same manner as fabric formwork. Previous research studied the multiple manufacturers that are currently offering 3D printing filament and can be referenced to identify which material had the highest rate of success (Peters 2014).



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MATERIALS: CASTING

Two materials have been cast during the prototyping process (Figure 1). First, mortar mixtures (sand, cement, and water) that have no additives or composite materials added to the mixture have been used in the small scale molds. The resulting casts have a smooth texture with minimal imperfections. The structural capability of these casts has not been tested in a lab. Concrete mixtures (sand, gravel, cement, and water) will be possible as the system is scaled up and the mold sizes increase.

A second set of testing has used glass fiber reinforced concrete (GFRC). This material offers the potential of creating thin, detailed panels that have structural integrity without

Figure 1: Concrete (left) vs. GFRC (right)

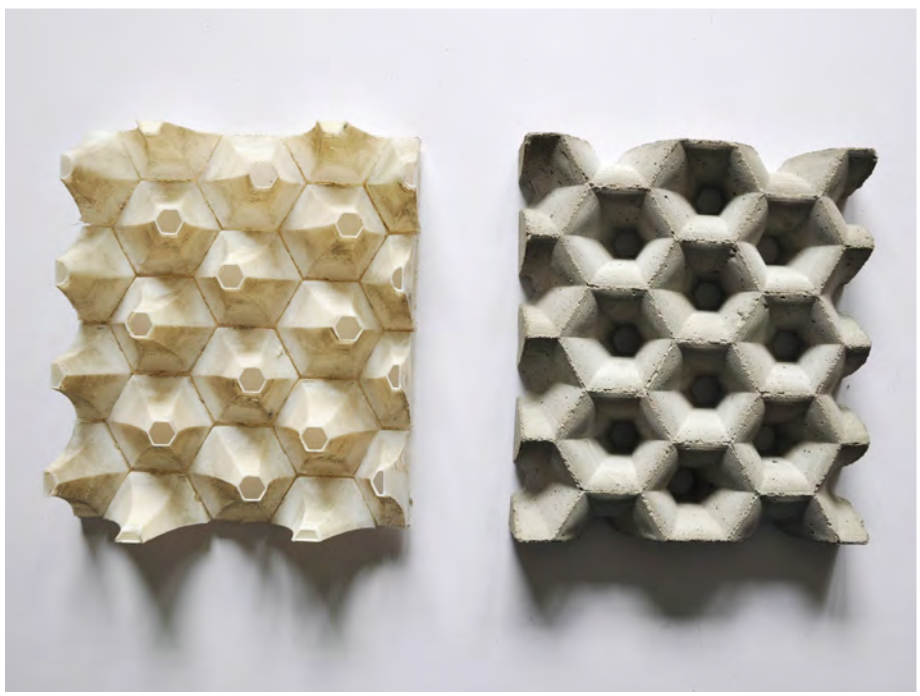
additional reinforcement. The GFRC casts also have a smooth texture with minimal imperfections.

The intent of Flex.Molds is to develop a mold fabrication technique that can rely on conventional casting processes. The material tests have shown that industry-standard casting materials work well with the system.

PROTOTYPING

All the prototypes for this research were 3D printed in-house. This direct link between the digital models and physical tests was essential for the Flex.Molds research, since working with and controlling the printers ourselves led to a better understanding of the material and fabrication opportunities and limitations presented by this system. Optimal printing parameters could only be determined through several rounds of prototyping and casting. The following factors were examined when prototyping: structural stability, permeability, printing speed, and surface delineation.

The prototypes were made on 3D printers with single extrusion heads, however dual extrusion printers could also be used. This system allows for the use of dissolvable PVA materials to be printed simultaneously with the flexible material. The dissolvable material acts as a support during the printing process, allowing for the fabrication of otherwise difficult geometries, such as large overhangs between layers. While this system eliminates some design limitations, it significantly increases the overall fabrication time and post-production of the prints. Therefore, the prototyping has focused on a single material extrusion system.



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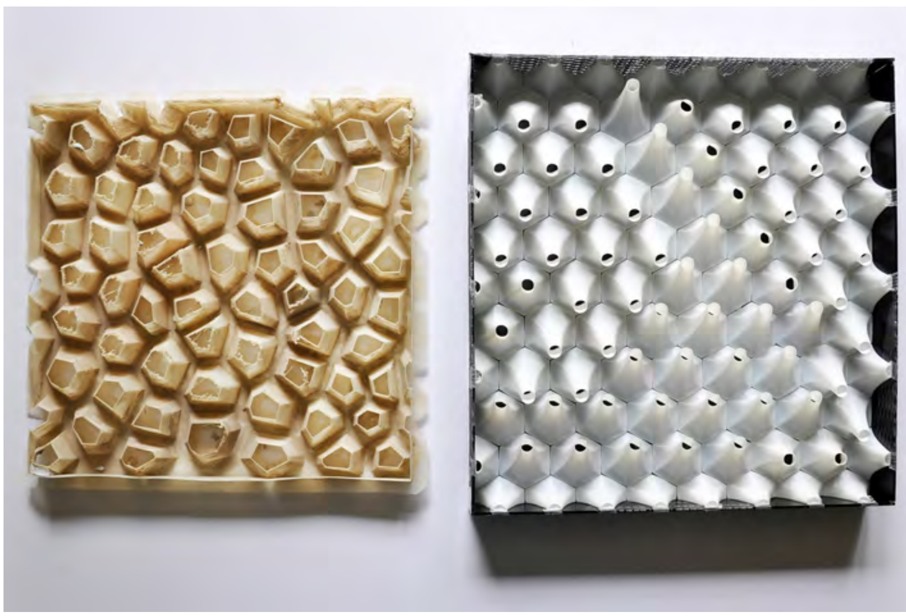
DESIGN

Combining parametric design tools, such as Grasshopper®, with 3D printing, allows for the creation of unique 3D prints and infinite design outputs for concrete panels. Not only are the molds flexible, but the design opportunities are flexible as well. The initial designs produced for the research focused on two primary application categories, interlocking

Figure 2: Reconfigurable mold layout

blocks and wall panels, to understand the opportunities and limitations of the material and fabrication system (Peters 2014). The interlocking blocks have intricate exterior patterns and are intended for wall or roof applications. The wall panels include both solid and perforated panels. The solid panels are intended for wall veneer applications and the prototype designs study various patterns and effects that could be applied. The casting technique for these panels is similar to that used for form liners. The perforated panels could be used in shading or rain screen applications and various geometries were developed to test their feasibility.

Since then, the research has focused on identifying geometries and applications that highlight the potential of the technique. For example, the new tests are exploring the use of "under cuts" and complex geometries that can only be achieved with advanced fabrication techniques, such as 3D printing and multi-axes milling machines. The new prototypes also highlight the use of intricate interlocking joints, which could not be fabricated using any other tools. Finally, prototyping has also extended to the design, fabrication and casting of two-part molds. The success of these tests points to the possibility of casting large and complex geometries that would far exceed what is possible to 3D print in a single mold that uses a form liner technique.



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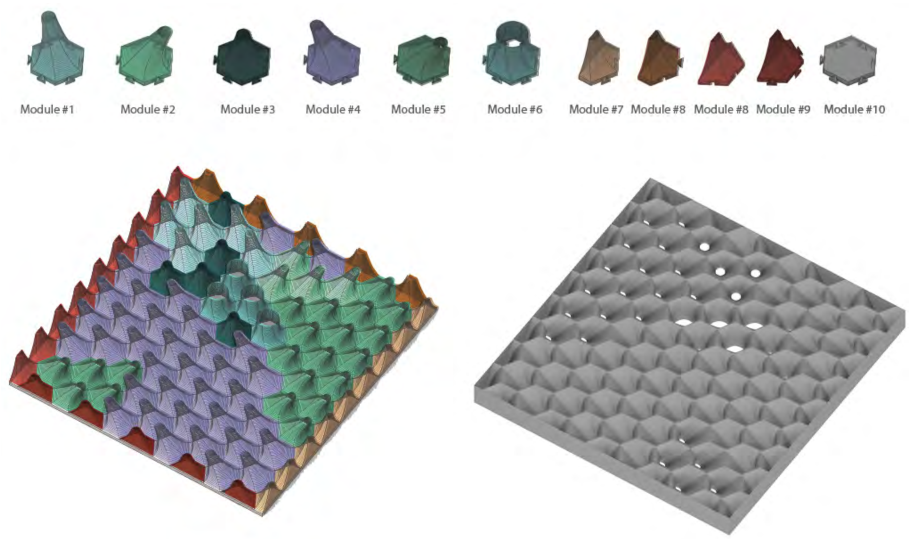
RECONFIGURABLE MODULES

Currently, fabrication time is one of the disadvantages of this system. Experimentation led to an innovative method for efficiently producing large panels: reconfigurable modules (Figure 2). For example, to produce a 24in x 24in x 2in panel, option one would be to 3D print a large scale mold in one piece and option two would be to 3D print several small interlocking modules that assemble to form a mold at the desired size (Figure 3). Comparing the initial fabrication time of these two options, the single mold is faster to produce (42 hours vs. 50 hours), however, if a design calls for 20 unique panels across a surface, the calculation changes. Since the small modules are reconfigurable, after they are cast and the concrete is removed, they can be reassembled into countless combinations to create unique variations. The mold fabrication time then becomes 840 hours for 20 unique, monolithic molds and still 50 hours for 20 unique molds made from the small reconfigured modules.

Reconfigurable molds also solve another problem. Molds can break or delaminate during the casting or removal process, rendering the mold unusable. When using reconfigurable

Figure 3: Monolithic vs. reconfigurable



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molds, only the individual module that was damaged needs to be reprinted, thereby creating less waste and reducing additional fabrication time.

The panel system shown highlights the design potential of such a system (Figure 4). The application is a sunscreen façade that can be configured to respond to specific sun angles, controlling the quantity of sun exposure in the interior at certain times of day throughout the year. The various modules each represent a specific time of day during the year, so that sun exposure can be tailored to the building's site, façade orientation and desired interior effect. Several parameters of the design can be modified, including the sun angle, the size of the perforation (or no perforation at all), the shape of the perforation (circle, square, etc.), and the depth of the panel. Additionally, the outlining frame can be changed to create a different size panel or to create a different shape, such as an octagon or triangle, all while using the same modules. The system is also easily scalable, meaning that the reconfigurable modules can easily be designed for larger or smaller panel sizes, perforations or thicknesses. The modules use an interlocking snap fit connection that allows them to be held together temporarily during the casting process, but then easily released after, allowing them to be reassembled and reconfigured into a different casting pattern. The snap fit connection is a custom detail, and therefore several rounds of prototyping we necessary to achieve the ideal tolerance that leads to a tight fit between the modules, but that doesn't cause damage when they are separated.

ONGOING RESEARCH

Flex.Molds began with research into both the printing and casting material with the goal of identifying important parameters to create a reliable fabrication system. While this research is still ongoing, the focus is currently on the design outputs that can be achieved with this technique, as well as the development of the interlocking and reconfigurable modules. The durability of the formwork during the casting process also merits further experimentation, as stresses put on the molds include the placement of reinforcement and the use of release agents. To date we have cast several molds up to five times and have seen very limited damage to the mold, however this will continue to be monitored.

The research has been focused on small scale prototypes, and therefore the next step of the project will be to cast large scale panels (Figure 5). These will test the limits of the fabrication process, as well as the structural capability of the molds and panels.

Figure 4: Reconfigurable mold design

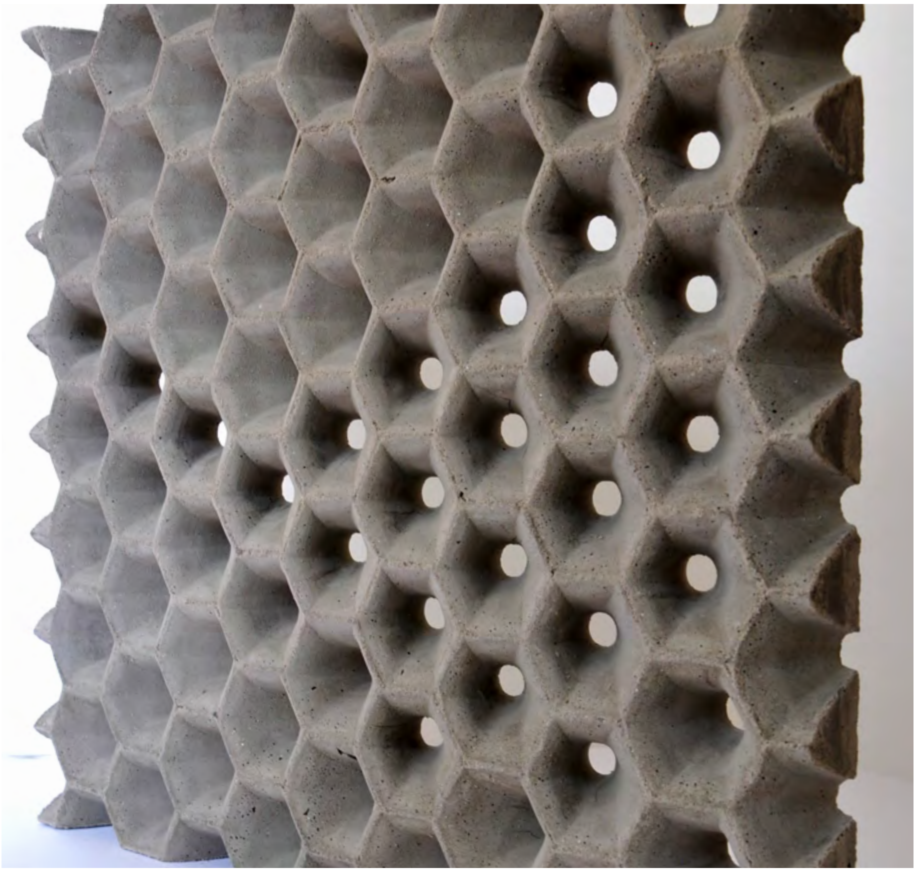

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Figure 5: Concrete cast

CONCLUSION

Flex.Molds offers a new pathway for 3D printing to improve an aspect of architectural construction. Unlike directly 3D printing a structure, this method has the potential to be implemented immediately into the construction industry because it improves upon an existing, well-understood technique and material. This research also serves as another example of transforming 3D printing from a prototyping tool to a manufacturing tool that produces functional objects. There are several benefits that we see to using this system in comparison to directly 3D printing a panel or using typical precast methods. These include highly detailed surfaces, fine surface finish, complex geometries (under cuts), reconfigurable modules through the use of interlocking joints, high material efficiency and the potential to recycle the mold after its usefulness. At the same time there are several limitations to this technique, which include slow fabrication time, limited printer sizes, and the durability of 3D printing (delamination between layers).

Another important advantage is that 3D printing unique molds does not increase the cost of fabrication. This allows for the production of highly complex or intricately detailed forms, which greatly increases the design possibilities for architects. Designs that would otherwise be simplified to fit a small number of molds can remain as the architect intended them to be. Additionally, this technique directly 3D prints the form that will be cast, and therefore the traditional step of CNC milling a form from which to make the mold is not needed. Eliminating this step helps to compensate for the main disadvantage, which is that 3D printing is a slow process.

GUIDELINES

These guidelines are for architects and fabricators to reference when using flexible filament to 3D print forms for casting. Through several rounds of prototyping, several key parameters were identified for working with the technique, however note that these guidelines are in reference to FDM style 3D printers only.

PRINTING SPEED

The recommended printing speed for flexible filament is 30mm/s. This is significantly slower than the printing speed for standard PLA filament (50mm/s), to reduce the amount of printing failures during the fabrication process. Additionally, this significantly increases the overall fabrication time compared to typical a typical filament.

OVERHANGS

One of the biggest limitations of using a FDM style 3D printer is the minimal tolerance for overhang between layers. Through our research we have concluded the maximum angle for the overhand between layers with a single extrusion system is approximately 45 degrees.

LAYER HEIGHT

The surface finish of the concrete is directly related to a printing parameter: the layer height. For example, when printing with desktop 3D printers, a layer height of 0.1mm should be used to create a relatively smooth surface finish, with the printing process almost undetectable. However, the surface finish for molds created using robotic arms with a larger printing nozzle is slightly rougher, since it is necessary to have a layer height of 1.8mm.

The layer height affects both your surface finish and your overall fabrication time. The smaller the layer height, the finer the print resolution and surface finish and longer the overall fabrication time. The larger the layer height, the rougher the print resolution and surface finish, however the quicker the fabrication time. The majority of the Flex.Molds prototypes were fabricated with a 0.1mm layer height.

WALL THICKNESS

Prototyping has led to a recommended wall thickness of .8mm to 1mm. This allows for the layers to properly adhere, producing a fairly durable mold that withstands repeated castings.

SURFACE DIVISION

Large, flat surfaces tend to warp during the printing process due to the properties of the material, which can ultimately lead to a print failing during the printing process. To avoid surface warping, large surfaces should be subdivided into smaller geometries. An additional benefit to this approach is that the vertical sides of the mold also become stiffer, which is important during the casting process. The correct amount of surface division depends on the overall scale and design of the mold to be fabricated; therefore it is not possible to provide definitive guidelines for the size of the subdivisions.

PRINTING MATERIALS

The previous research on this topic studied the multiple manufacturers that are currently offering 3D printing filament to identify which material worked the best (Peters 2014). Generally speaking, there is a much higher rate of print failure when using flexible material compared to a standard hard plastic, such as ABS or PLA plastic filament, because of its sensitivity to the parameters noted above. It is necessary to be patient with these prints and expect a certain level of failure during the prototyping process. FlexiFil™ filament produced by FormFutura has been the most reliable, however results will continually vary as manufacturers update the materials.

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Applicable Experiments: Collaborative Models for Material Research

Before the 19th century, a buildings tectonics was largely unified. Categorical distinctions among so-called "systems" - structure, enclosure, interior and exterior walls, and circulation were unknown. All of that changed with the advent of the steel frame - vertical circulation, environmental systems, clad surfaces, and curtain walls, newly liberated from any structural role, could be internalized, enclosed, encased, and hidden within other concealing floor plates, walls, and ceiling voids.

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Throughout 20th century moderism, little effort was made to revive any sense of tectonic unity, despite new technologies and materials. However recent architecture and buildings of the last decade have begun to explore more ambiguous, hybridized, even blurred convergences of structure and surface. While norms of construction, fabrication and assembly still favor isolating building components, architects are now producing buildings whose elements if not reunified - are far from prevailing dogmas of tectonic isolation or structural separation. If we characterize this prevailing separation of structure and skin of the last century as the thinning out among discreet spatial components with separate identities, perhaps the current focus upon mixed or recoupled elements suggests a thickened reunification of structure and skin. What if structure was no longer internalized, but externalized and brought to the outside? What if bearing itself became less localized or isolated and was dispersed across surfaces that were no longer just columns, floor plates, circulation, or façade alone? It is from these initial questions that the author's research emerged - what would a space of merged tectonics look like using steel, the very material responsible for promoting tectonic separation? How would it be done and how would we as architects need to organize ourselves to effectively engage with 21st century technology and manufacturing?

INTRODUCTION

This article will present strategies for forging collaborative architectural practices between universities and manufacturing industries. It will focus on current architectural research, its explicit impact on manufacturing processes, and the influence of these processes on design outputs. Specifically, the authors will discuss examples of collaboration between faculty and students at the University at Buffalo Department of Architecture, and manufacturing industries initially based in the Buffalo, but more recently, a network of architects, manufacturers, and engineers, spread across the globe. These include: 1) the initiation of a working relationship between the Department of Architecture and the world leader in deep-textured metals manufacturing, Rigidized Metals Corporation, through the development of a student design competition and graduate design seminars, 2) the development of further research by faculty and students on the structural capacities of folding stainless steel and the development of an experimental prototype, project 2XmT, that demonstrates the aesthetic potential of this research, 3) project 3xLP, the winning submission to the international TEX-FAB SKIN competition that coupled the authors and Rigidized Metals with material and fabrication support from A. Zahner Company and engineering support from ARUP, thereby rapidly expanding the reach and momentum of an emerging research practice, and (4) forging new collaborations with manufacturing companies spread more broadly across the globe, specifically the Absolute Joint System (AJ) based in London, England, allowing our team to integrate a wider range of materials and digital technologies into our workflow, while moving our research toward a marketable product.

Using the framework outlined above, this article has four thematic objectives: to describe the procedures by which two faculty developed, designed, and fabricated a prototype in collaboration with an industrial manufacturer, and utilized the described framework in developing a proposal for an intense collaboration; to identify how architects are utilizing digital tools to facilitate collaboration among diverse Architecture, Engineering, and Construction (AEC) teams with the goal of merging design and construction into an integrated workflow; to catalog how new means of interfacing with information and an increased proximity to the production of products/objects through CNC machinery is radically reshaping a renewed material-centric practice in architecture and its related fields; and to assess the capacity of parametric design software and how this method of working/thinking has allowed architects to streamline drawing-to-production methods.

MODEL 1: FACULTY AS ORGANIZER

The first collaborative model begins on campus under a loose pedagogical theme to explore architectural applications for a local textured metals manufacturer based in Buffalo, NY, the Rigidized Metals Corporation (RMC). The company is unique for their cold-rolling process of embossing geometric textures into thin gauge metals. The approach was strategically split between two graduate seminars, one being led by Nicholas Bruscia which focused primarily on specular effect through subtle geometric variation (patterns and folds) and the other led by Christopher Romano which focused on self-structuring thin-gauge metal surfaces using similar methods. It was an exploratory phase with students testing a number of preliminary issues that were based on individual interests: unrolling geometric surfaces, folding metal, and mapping a range of specular qualities inherent in the metal. This semester-long process included a tour of the manufacturing facility, an introduction to the material and manufacturing process by Rick Smith, president of the company, and week-to-week feedback provided by the course instructors. This structure resulted in a series of student-groups working collaboratively on small physical prototypes using the tools and technology available to them within the university to simulate the effects of rigidized metal and the fabrication workflow of the manufacturer. There were no monetary or logistical risks assumed by the manufacturer, as the large majority of the research was being conducted within the university. At the conclusion of the semester, students presented their work to the president of the company and a small group of administrative staff at RMC.

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Figure 1: Student assistant working on full-scale prototypes, Materials and Methods Shop, University at Buffalo, Department of Architecture

To begin to unpack the initial benefits of this type of interaction, the manufacturer had a large group of students, near graduation and about to enter the workforce, touring their facilities and learning about their product which alone is an enormous benefit to any manufacturer. In addition, students free from any economic or logistic constraints were able to ask questions, design freely, and introduce contemporary parametric software to the manufacturer, which we felt could be of potential use to the manufacturer in the future. As a model that is implemented in the initial phases of a manufacturing relationship, it is useful for the structure to be more traditional so as to allow the academy to engage with imaginative ***thought experiments*** based on ***real-world material contingencies***. The advantages for all parties emerge naturally as the relationship moves away from students, faculty, and manufacturer's simply using new information toward the completion of a single self-guided project, to the production of new knowledge whose ultimate goal is real-world applicability.

MODEL 2: FACULTY AS MATERIAL RESEARCHER

The second collaborative model proposes a faculty-directed research structure that allows the Department of Architecture and local and regional manufacturing to collaborate on the development and full-scale testing of architectural applications for their product line. This includes finding new potential in existing products, the development of new techniques, and the optimization of existing processes through the use of digital tools for both design and fabrication. The research collaboration detailed below is used to explain how this model builds on prior collaborative work completed within two graduate technical methods seminars described in Model 1, while synthesizing these pedagogical approaches into a singular research proposal.

In this model, much of the effort is twofold - material testing a manufacturer's existing product line and attempting to extract the unwritten knowledge that collectively exists amongst the manufacturer's fabrication team. A challenging, yet crucial next step is attempting to document this data in a quantifiable and measurable format that can be used to inform future design decisions. To that end, we conducted extensive testing: photographic documentation of the exterior light reflecting and diffusing qualities of textured metal under a range of weather conditions, strength comparisons of plain stainless vs. textured stainless, 3-point deflection testing of some of the more common patterns to pinpoint which patterns yielded the highest structural performance, and extensive metal folding studies to reveal to the academic team the fabrication limits of both the hydraulic turret punch and hydraulic press brake. This testing yielded a decision-making process that was based on empirical data instead of relying on rule of thumb or repeated cycles of trial and error.

To understand how the research was framed, it is important to have a more detailed understand of *rigidizing* as a manufacturing process - rolling geometric textures into ordinary sheet-metals to increase the cross-sectional depth of thin-gauges by distributing metal above and below the neutral axis, resulting in a much stiffer material and providing thinner and lighter gauges with increased structural capacity. At the same time, the process gives the material dynamic light diffusing qualities, suppressing oil-canning and resulting in superior optical flatness and uniform aesthetic appearance. To summarize, both specular quality and surface rigidity result from the same geometric conditioning of the metal – a material characteristic that had not previously been studied or exploited. Prior to our collaboration, the exclusive use of this material had been for non-structural façade elements or interior panels backed by substrates, the intention of this research is to develop a self-supporting architectural system that reveals the existing, but underutilized, structural potential of the material while simultaneously exhibiting the specular quality of the texture. Our research culminated in an experimental prototype, *project 2XmT*, which uses a framework of arrayed octahedrons and thin-gauge rigidized metal to generate a self-structuring skin that exhibits extreme physical and visual lightness. Based on the textural qualities of the metal and the principle of triangulation, specifically through the use of an expanded diagrid, the authors invented an ultra-thin, woven "face-frame" - a space frame

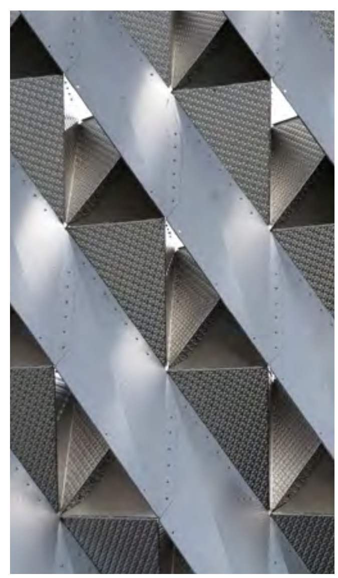
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Figure 2: *project 2XmT* - detail of rear elevation showing expanded/woven diagrid and the combination of metal textures

3

turned into surfaces where instead of connective nodes, overlaps in the surfaces make for a more continuous and more effective connection by better distributing the forces moving through the metal. What is made clear through this work is that the rigidizing process simultaneously creates a visual and structural potency, making large scale thin-gauge assemblages possible.[1] At a height of 19’-6” (5.8m), project 2XmT is the world’s-largest self-structuring surface, and to our knowledge we can use this framework to scale up infinitely.

As a collaborative approach, project 2XmT can be compared to the Los Angeles County Museum of Art’s (LACMA) original Art and Technology program, which ran from 1967 to 1971. Curator Maurice Tuchman invited artists to be matched with companies working in industry; pairing Tony Smith with the Container Corporation, a manufacturer of paperboard products including folding cartons, paper bags, and fiber cans. Up until that time, most of Smith’s sculptures were generated from modular-based paperboard components, typically tetrahedrons or octahedrons, but the component nature of his work became invisible once the work was fabricated in steel at a much larger scale. Working with the Container Corporation, he could replicate his method of working at a monumental scale - resulting in a 2,500 unit cave-like exhibition for the U.S. Pavilion at Expo ’70 in Osaka, Japan.[2] As in our case, the installation achieved a more precise level of clarity when artist and industry collaborate on research.

This model of collaboration, closely aligned with the academic, privately-sponsored research project, requires a great deal of time to frame the research in a manner that is mutually beneficial to all parties. Working agreements are signed that outline the scope of the research, project expectations are agreed upon, and monies exchange hands to execute the research. In working with RMC, it became clear that the project would entail far more oversight from the manufacturer, would require regular meetings with the fabrication team, and that we would be integrated into the monthly production cycle as if we were a paying customer. As a model, it requires financial support, large quantities of raw material, and high demands on machine time and human labor. But, if successful, the research would dramatically increase the visibility and marketability of their product line. In addition to the potential marketing benefits, it was equally as beneficial from a technical perspective. The digital tools we were introducing were not part of the day-to-day workflow

Figure 3: *project 2XmT* - front elevation view of the 19’-6” tall, 152 panel *face-frame* prototype

of the manufacturer, which has since changed as the result of our work and our attempt to demonstrate their relevance in advanced manufacturing. Furthermore, by discussing the project in a parametrically-controlled digital model, architects and fabricators are able to speak the same language and clearly visualize information. This three-dimensional conversation allows the fabricators to work off more accurate base files, reduce mistakes, and thus minimize risk. It also results in better coordination amongst team members and in a faster fabrication schedule. For our team, this digitally-based workflow reinforces our appreciation for mathematics, allowing us to be more creative and explore more complex geometries that were not familiar to the fabricator, thus spending additional time on design that would have otherwise been dedicated to project coordination. More importantly, this collaboration allows us access to cutting-edge machinery and the ability to test ideas at a much larger scale than previously possible, re-centering the material mockup as a crucial and necessary part of the architectural design process.

MODEL 3: FACULTY AS CONDUIT

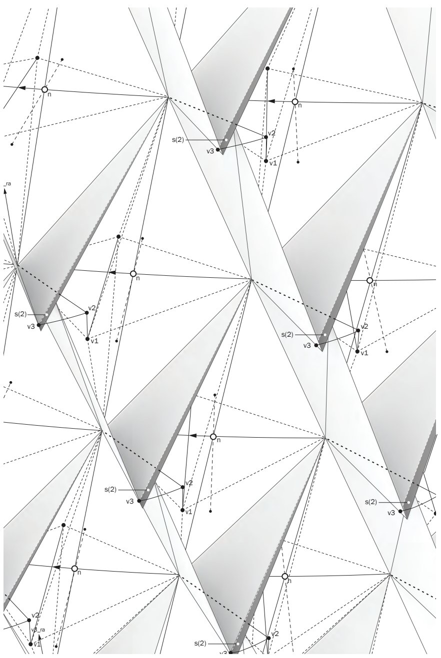
The third collaborative model was a two-day specialized workshop which was part of the 2013 International ACADIA Adaptive Architecture Conference. The workshop covered topics ranging from scripting, simulation of complex systems, and digital fabrication with advanced manufacturers. As workshop directors, we were interested in getting students and professionals to interact directly with the fabrication team with the primary goal of getting participants on the factory floor with the people who make things, observing the process of how their drawings are translated to generate CNC code that can be read by the machinery in the facility. For many participants, this is their first time on a factory floor exploring a type of making that is unfamiliar to many of them: making with very-large machines. At a minimum, we wanted participants to understand how to effectively communicate with fabricators.

Throughout the two-day workshop "*Rigidized Metal Forming*," we were tasked with consolidating what we had learned in one year into a 48-hour period, taking students through the entire design-to-fabrication process. Participants were constantly moving between analog and parametric modeling, realizing a small, but critical lesson as stated by the French engineer Robert Le Ricolais, "The art of structure is about where to place the holes." Even in a very brief period of time, the opportunity to speak directly with fabricators, touch and feel the metal, and assemble a prototype of their own design changed the way participants thought about material and fabrication. In addition, the manufacturer's affiliation with the ACADIA community gave their product wide exposure both domestically and internationally through the hundreds of student, academic, and professional attendees from around the world. The workshop model is an effective method for closing the gap between the academy and the profession and perhaps more importantly, breaking from the traditional university course structure of meeting once or twice/week for 15 weeks. From our experience, the workshop model is based on brief, but uninterrupted periods of intense learning, and is able to produce similar results in terms of output and quality when compared to typical university coursework, such as described in Model 1.

MODEL 4: FACULTY AS TACTICIAN

The fourth model of collaboration was a repeat of the latter half of Model 2 (Faculty as Material Scientist), except that it was now a long-distance collaboration amongst many parties involving a commissioning agent serving as the role of client, a number of universities that make up the TEX-FAB Digital Fabrication Alliance, A. Zahner Co. as fabrication sponsor, and ARUP as engineering sponsor. The project needed to be completed in a matter of weeks, not months, thus we saw ourselves in a new role - that of tactician, with a large majority of our time and energy dedicating to managing the relationships between a greatly expanded team of stakeholders. An added challenge was that this research would have to be conducted remotely with very little face-to-face communication which was vital to the success of previous models.

As part of our TEX-FAB SKIN competition winning entry, *project 3xLP*, we were granted the opportunity to build a second iteration of our SKIN prototype, refining and experimenting with our self-structuring system to introduce visual porosity while maintaining structural stability. Our first assignment was to negotiate bringing Rigidized Metals onboard as both co-material and co-fabrication sponsor. This strategy allowed us to continue to work with the material central to the research, and not knowingly, more than double the funding available to execute the second prototype, thereby increasing the scale and scope of the second prototype. With little time to build physical mock-ups, we opted to digitally simulate the effect of physical forces with the assistance of Maria Mingallon, a structural engineer at ARUP, performing an initial round of FEA analysis on the second prototype, creating a feedback loop between digital model, our first physical prototype, and stress-based FEA analysis. Stated Mingallon, "The results of the digital analysis demonstrated that the origami-like strategy would make the wall strong enough to deal with the typical design loads applied to medium-height buildings."[3] This feedback provided a level of confidence that we could apply this system at a much larger scale and as a contemporary façade solution.



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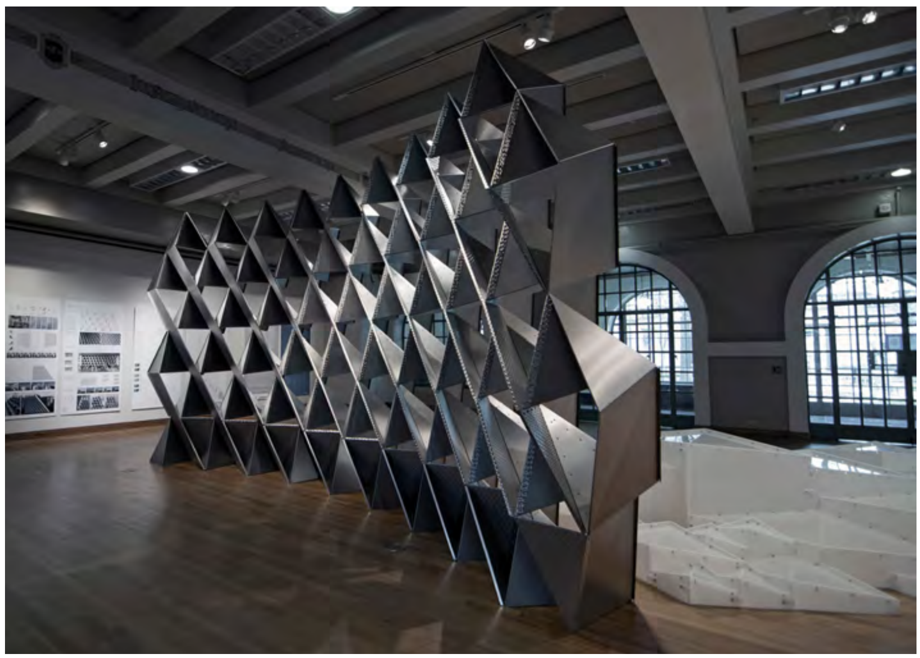

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As mentioned above, this collaborative model was about speed, expanding outreach, and relying on external expertise to complete the project. There was little time to meet in person, to design, to prototype, and to make a fabrication error that would alter the production schedule. In doing so, our three-dimensional modeling got tighter, containing more precise data regarding part numbers, geometric families, patterns, gauges, grains, finishes, and assembly sequence. Our need for traditional drawings was dramatically reduced (but not eliminated), resulting in time gained for iteratively testing design solutions and resolving details to achieve tighter fabrication tolerances. We also began to optimize design parameters to find a suitable balance between geometric variation, machine time, and human labor. The competition platform provided a showcase to demonstrate the

Figure 4: *project 3xLP* - partial view of drawing showing geometric parameters and variation

Figure 5: *project 3xLP* - rear elevation view, Tex Fab 5 - SKIN: Digital Assemblies exhibition, Austin Texas

fabrication capacity of two expert manufacturing companies. Repeating the process strengthened and solidified our working relationship with RMC, while allowing us to collaborate with A. Zahner Co., a world leader in metal façade manufacturing. From a marketing perspective, the benefits were measurable as the results were included in various print/online publications and numerous contacts were made within Texas.

MODEL 5: FACULTY AS PROCESS ENGINEER

The fifth model of collaboration is a joint-venture partnership forged between a public research institution and a privately-held company, latter one focused primarily on the development of large-scale, modular building structures and the former, primarily on the development of innovative building skins whose collaboration attempts to further develop a more marketable product that could be more widely distributed in global architectural contexts. In early conversations, both parties were interested in forming an interdisciplinary partnership that would merge the two threads of research together to form a more holistic system that could deliver architectural solutions for both structure and skin.

The authors teamed up with Bartolomeo Mongiardino and Alessandro Traverso, mechanical engineers based in London, England, and inventors of the *Absolute Joint System* (AJ), one of two non-welded, round pipe, stainless steel structural systems in the world. More specifically, AJ is a dismountable and reusable space frame system with members connected by means of custom spherical joints. Targeting reusability in lieu of recyclability, the AJ system is a highly durable kit-of-parts for small and large scale space frames that can adapt to a wide-range of spatial configurations to reduce waste and minimize the embodied energy required to create building structures.[4] Our collaborators recognized that there is an increase in the production of temporal programs that require large expanses of column-free space, such as temporary shelters, storage/transportation facilities, and large stadiums whose intended lifespan may be shorter than traditional buildings. In contrast to the costly maintenance and (often times) infrequent use of these permanent structures, the dismountable AJ system proposes an alternative approach to construction.

In response to the agenda set by B. Mongiardino and A. Traverso, the work was summarized very broadly, working simultaneously towards three goals: 1) to increase the feasibility of the AJ System, 2) troubleshoot their existing web-based product offering, and 3) test their structural system against a range of geometries, enclosure systems, and panelization options. Currently, we are focusing on the development of surface optimization and efficient panelization using rigidized metal that can adapt to multiple configurations. Similar to the concept of the AJ system, we are attempting to develop a series of identical panel families that can be applied to formally distinct free-form surfaces. By designing a kit-of-panels, we are attempting to construct a full-scale mock-up that explores reusability in large-scale architecture: a reconfigurable kit-of-parts, structure and skin, that can be mounted and dismounted, packed in a cargo container, shipped across the globe, and reconstructed in a range of configurations.

For the authors, this work has many benefits. It is research that directly engages in the construction industry to develop solutions that find efficiencies in problems that have existed within the discipline for decades. At the same time, this collaboration furthers the research, moving beyond the initial question of self-structuring of thin-gauge, textured stainless steel to addressing questions about enclosure and a higher degree of performance. In addition, it allows the work to move toward a marketable product that could very quickly reach a global audience and do so at a large-scale. For RMC, it is an ideal application for their deep-textured products: lightweight, durable, and highly resistant to visible scratching, making it ideal for structures that are repeatedly assembled and dis-assembled. For the AJ Team, this collaboration gives them a base of operations in the United States, a manufacturing partner in RMC, and the ability to test their system on a range of complex geometries prior to entering into the highly competitive material manufacturing market.

MODEL 6: UNIVERSITY AS INCUBATOR

In this last model of collaboration, our role shifts from faculty-directed research to that of architectural consultant with workflow moving through the manufacturer. In the contemporary AEC industry, there is a reoccurring pattern where clients are looking for the manufacturer to provide in-house expertise to solve technical and logistical issues that arise throughout the design and implementation process. As the research moves from sponsored-research to for-profit commissions and consultations, we have found a usefulness for a young design practice that can move fluidly between a design-assist and a design-led format depending on the scale, scope, and scheduling of an incoming project. When not acting in a traditional architectural role, we operate as an alternative mode of practice, hovering between academia and industry, and thus able to provide a number of alternative benefits: mediating between architects and manufacturing throughout all phases of the design process, teaching sales and marketing teams about emerging technologies in architecture, and focusing on commissioned work that exists somewhere between the scale of installation and architecture. This newfound capacity allows RMC to take on work it would have otherwise turned away, thereby increasing internal capacity and allowing a greater audience access to their product offerings. In this scenario, both university-supported and industry-supported work generates an incubator where young design practices can balance their intellectual curiosity with 75 years of industry expertise.

CONCLUSION

In conclusion, these are models that we are exploring as alternative modes to traditional architectural practice. The models suggest that these are not idiosyncratic moments/ relationships, but rather, educational, research, and practice models that can be replicable in other locations, with other companies, and sustained for the long-term. Although each of these models are capable of standing-alone, they can be performed in succession as a relationship-building strategy, or they can simultaneously overlap, where one model can serve as a test-bed for the other. Nonetheless, it is through initiating a conversation about computation-tied-to-making that we are able to directly engage in the supply chain, allowing architects and manufacturers to develop a collective-intelligence and a highly collaborative workflow. Through the use of these organizational models, parametrically controlled three-dimensional modeling, and an extreme attention to detail in the manufacturing process, we argue that we are increasing the scope of architecture - taking control of project delivery back into the realm of the architect and reconstituting a high level of craft through intense collaboration with manufacturing. It is through this confluence of interests in both digital technology and contemporary industry that has offered us a way to push forward an alternative trajectory of architectural research and practice.

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Housing Shrewdly/Unhurried Building

shrewd

1. *Having or showing a clever awareness or resourcefulness, especially in practical matters.*

2. *Disposed to or marked by artful and cunning practices; tricky.*

3. *Archaic* Sharp; penetrating: *a shrewd wind.*[1]

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INTRODUCTION

Educational Design-Build (EDB) has exploded in popularity over the last twenty years especially since it was reinvigorated by Samuel Mockbee's Rural Studio at Auburn University in 1994.[2] Although they may be unique to many practicing architects today (who often say "I wish I had a project I actually got to build in School"), EDB programs and projects are found at over 2/3rd's of the 154 schools of architecture in North America today.[3] These projects and experiences have come to be expected by today's students who want to be involved from the initial conceptual design to installing the kitchen sink. EDB at its best, combine's civic-minded, design education with project-based real-life experiences. These projects tend to be perceived as a proverbial "win-win" for all involved - students, faculty, clients, and the community. However, there are many difficulties and thus lessons that are not usually researched, examined, and presented in full light.

Three houses designed and built by architecture students at the University of Louisiana at Lafayette exhibit shrewdness in their clever manipulation of the ubiquitous forms and materials of southern Louisiana. These design manipulations lead to the distillation of memories and familiar associations for the viewer and inhabitants. The student designers were acutely aware of what Juhani Pallasmaa describes so aptly: "…architecture withers when it departs too far from the primary experiences and images of dwelling." [4] The EVENT, NEXT, and COUR houses were each built for approximately $115 per square foot and achieve LEED and Green Building equivalencies.[5] As the first homes in their respective urban core neighborhoods in the last thirty years, they were sold at comparable market rates and have been embraced by their communities as successful, sustainable and affordable models helping to revitalize their environs.

UL Lafayette's Building Institute's Neighborhood Infill Housing Program has received many accolades including awards and celebratory press.[6] The three homeowners are all very content in their homes and all the students who worked on the projects have found successful architectural careers.[7] However, like all programs with many moving parts, some aspects presented great difficulties. These difficulties paired with other unavoidable circumstances have placed the program on temporary and possibly permanent hiatus. Although the Neighborhood Infill Housing Program presents a successful model for teaching architecture students, neighborhood revitalization, and producing affordable and environmentally-sustainable housing, it may not itself be sustainable in its current form.

UNIVERSITY OF LOUISIANA AT LAFAYETTE BUILDING INSTITUTE

The UL Lafayette Building Institute is an integrated project delivery/develop-design-build program. The program brings clients, architecture students, architects, engineers and contractors together in the design and construction of homes, installations, and community architecture. The Building Institute is structured through a graduate design studio in the fall, a construction documents course in the spring, and a construction course in the summer. Students receive academic credit for each course and in addition, several team leaders receive internships allowing them to accrue IDP credit. The Building Institute is not a simulation, it is hyper-reality. The constraints are not just "real-world" but often exceed the experiences found in professional practice. As architect-builder-developers, the students become agents of change. The thirty designed and built Building Institute projects total approximately $2 million.[8] The projects range in size from puzzle/game boxes for Hurricane Katrina evacuees to the BeauSoleil Louisiana Solar Home, UL Lafayette's award-winning entry in the Department of Energy's 2009 Solar Decathlon.[9] The Building Institute was founded together with Professor Emeritus Edward J. Cazayoux, FAIA in 2002.[10]

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NEIGHBORHOOD INFILL HOUSING PROGRAM

Following the success of UL Lafayette's 2009 Solar Decathlon house, the BeauSoleil Home, the Lafayette Public Trust Financing Authority (LPTFA) approached the Building Institute and began formulating what would become the Neighborhood Infill Housing Program.[11] The Chairman of the Trust offered no-interest loans to the university for the purpose of building innovative, energy-efficient and sustainable housing prototypes in the urban core neighborhoods around downtown Lafayette, Louisiana.

UL Lafayette approved the concept and suggested that a non-profit entity, Ragin' Cajun Facilities, become the arm of the university acting as the client. Attorneys were consulted and agreements were drawn up between the LPTFA and Ragin' Cajun Facilities, between Ragin' Cajun and the Building Institute, between Ragin' Cajun and the building contractor, and between the contractor and the Building Institute. What was initially believed to be a simple arrangement became very complicated with four separate legal entities. A local

Figure 1: Building Institute's EVENT, NEXT, & COUR Houses

2

Figure 2: EVENThouse

mortgage company provided pro bono services in searching for properties in the urban core neighborhoods and in helping with title services. A pro bono realtor helped sell the homes. The proceeds were then used to repay the first loan and subsequent loans were taken out to repeat the process.[12]

EVENTHOUSE - PHOTO CREDITS ROBIN MAY

"I believe that an early integration of students with contractors is an excellent way to open student's eyes to the realities of construction and cost estimations. Also, the process reveals the absolutely vital component to an architect's success at peaceably resolving issues with contractors."[13]

—Graham Goodyear, EVENThouse Student TEAM Leader

The EVENThouse followed in the footsteps of the 2009 Solar Decathlon house, the BeauSoleil Home. The LPTFA located a piece of property that the students began the design for in the fall of 2010. However, by the end of the semester, a new lot had been found in the LaPlace neighborhood, near downtown Lafayette. This lot was actually more prominent and larger than the first lot. Four students started the process by each doing precedent analysis and then developing a design. The best of the four designs was selected by the students and in fact the best aspects of each were incorporated. The students admired the transitional "dogtrot" porch of the BeauSoleil Home and this in turn influenced the Event space which was named for its ability to accommodate any daily events from greeting guests, to hosting a party, to doing a crossword puzzle.

During the design process, the contractor, an architecture alumnus, was asked to participate in critiques. In addition the LPTFA and PAR Realty were invited to offer advice based on the projected market for the home. A target market of a single individual, a young couple, or empty nesters was identified. The home was programmed as a two bedroom, two bath residence of about 1,300 square feet. The budget was set at $120,000 for construction not including the $10,000 property cost. Ultimately the project went slightly over budget and was built for $155,000.

> The Design-Build aspects of the Next House had huge implications on my career by creating a holistic awareness of the residential construction process. It also instilled a confidence to make design altering decisions in a timely manner."[14]
>
> —Jake Grandon, NEXThouse Student

Figure 3.: NEXThouse, Photo credits Haylei Smith

The EVENThouse revealed some of the difficulties but also gave the program confidence to continue in the fall of 2011. A lot was selected in Freetown, the up-and-coming artist neighborhood, also near downtown Lafayette. Hypothetical clients, such as the EVENThouse owner, provided input. A two story design was developed by a group of eight students. Again this lot fell through, a new lot was purchased during the spring semester, and an entirely new design was required because the lot was only thirty feet wide. As in the EVENThouse, construction documents were produced on Revit BIM software and negotiations with the contractor continued in the spring 2012 semester.

Once again the connection to the outside spaces was a conceptual driver in the design. In this case a front porch flows through the kitchen (since entertaining and cooking are so important in Louisiana culture) to the back porch. Overall the construction process was the least problematic of all three homes and when the summer semester was finished, the NEXThouse had been painted inside and out. The home was built for $145,000.

COURHOUSE - PHOTO CREDITS DENNY CULBERT & HAYLEI SMITH

> "This project taught me that you can never give up on a project, regardless of how far along you are if you want to insure the project will be built…Since acquiring a job, I respect and am more thankful than ever for my experience. I feel much more confident in my work and decisions that are made on a daily basis, and I am trusted with more than I ever expected at this point in my career."[15]
>
> — Nicholas Clesi, COURhouse Student TEAM Leader

4

Figure 4: CourHouse

The COURhouse design process began with great optimism. Two houses had been completed, the previous home's construction process had been more seamless, and the property had been purchased in advance. Because the property was larger and a market need for a three bedroom home was recognized, the programmed square footage was raised from 1350 square feet to 1,500 square feet. A team of six students analyzed the first two homes, the BeauSoleil Home, and other relevant precedents. The pressure was on them to raise the bar with this home. They also felt the need to invent a new typology.

The team investigated the suburban and urban typologies and determined that to attract a family to the Freetown area they would need greater privacy in this more urban setting. Therefore the courtyard typology was selected. Two contractors were consulted with from the beginning of the fall 2012 semester and eventually the two decided to collaborate on the construction. Once again the input of the LPTFA, potential homebuyers, and realtor were instrumental in assessing market needs and demands.

Construction documents and cost estimating were initiated in the spring 2013 semester and a contract was drawn up. Unfortunately, the university elevated the insurance requirements for the contractor specifying that they provide worker's compensation insurance for the students. The first contractors could not provide this so the team was left scrambling to find a new contractor. A new contractor was located but his bid came in $50,000 over budget. The team hurried to redesign and value engineer the cost of the home down. In the process concessions were handed over to the contractor and who took full advantage of these since many were not fully documented and revised on the drawings. The home was built for $170,000.

SUCCESSES

"The design and construction of the Nexthouse provided an opportunity for the architecture students to take part in a unique process that allows freedom in design while simultaneously exposing them to budget restrictions and market concerns…While they are more informed of the products, processes, and social benefits of conscientious collaboration, that is a comprehensive approach involving the management and coordination of many disciplines.[17]

Project-based learning requires collaboration, crisis management, and risk of failure. In the safety of the classroom the threat of failure is often farthest from the mind of the students. Out on the construction site or in a city council hearing, they are fully immersed in potential crises. As Trumble and Gjertson stated in Design-Build Gone South, "For students, professional ethics and maturity constitute major challenges and responsibilities. No longer are they allowed only to address their whims in hypothetical design. Actual humans are guinea pigs in EDB. Health, safety, and welfare is not an abstraction, it is required. But also professional attire, communicative skills, collaborative respect, and compassion are in the forefront. Student responsibilities have consequences which make them infinitely more memorable and salient than traditional studio projects."[18]

In addition to the education of students, the EVENThouse, NEXThouse, and COURhouse were intended to help educate the public through outreach, media and the establishment of a prototype. And the construction of the homes undoubtedly helped educate the contractors in new systems and processes. The homes serve as prototypes in their respective neighborhoods for high quality design and sustainable design. Contemporary examples of architecture are often admired in the latest periodicals but until they can be experienced up close and adapted to their particular culture and climate, they do not change societal or market attitudes. In addition, the homes provide "comparables" for appraisers allowing homeowners to more readily find construction loans in the future. Homes in their neighborhoods have sold for significantly higher prices since the introduction of the EVENT, NEXT, and COUR houses. And on just a basic appearance level, the new homes have inspired renovations or at minimum the repainting of adjacent houses.

In terms of sustainable, energy-efficient design, the homes consume approximately 50% less energy than other comparable homes in Lafayette with electricity bills of around $60 per month on average.[19] The outwardly "green" features such as solar panels also help advertise their viability in the community. Elizabeth Brooks, the owner of the COURhouse, sums up the features of her home as only a designer and planner can: "It affords me the opportunity to engage in conversations with interested residents about distributed infrastructure, and the benefits on the environment, as well as on my pocket book, which is critical for those who are looking to learn more before they invest in incorporating these techniques and technologies into their own homes."[20]

Finally, the Neighborhood Infill Housing Program encourages future public-private partnerships especially between the university and other industry and city organizations. When each organization aspires to higher goals such as public education and neighborhood revitalization, everyone benefits at an exponential level.

DIFFICULTIES

"…the more pernicious effects of an overbearing focus on a 'successful' build-at-any-cost can be that human-centered imperatives…can be overlooked."[21] - Stephen Verderber

It is relatively easy to list the successes and benefits of educational Design-Build projects like the EVENT, NEXT, and COUR houses. But obviously there are difficulties because the Neighborhood Infill Housing Program is currently on hold. Part of the reason is the lack of available and affordable infill property. However, there are more significant structural and philosophical problems that will need to be addressed in order to revive the program, such as:

STRUCTURAL DIFFICULTIES:

- Legal- four separate contractual agreements with many signatories and extensive approval processes
- Insurance- the need for full insurance coverage by the contractor for high-risk students
- Short Timeframe- one-year is a relatively short time for the design and construction of an innovative home, especially in the context of the inefficiencies of an academic setting
- Faculty Overload - an average of 12-15 hours per week above and beyond typical teaching, research, and service commitments for at least 7 months of each home project[22]
- Student Overload- students end up volunteering well-beyond the required time for their class/ grade, placing both student and faculty in a precarious position

INTERNAL SUPPORT DIFFICULTIES:

- The University does not always understand what the program is, how it works, or what its benefits are. This leads to unnecessary and redundant oversight.
- Attorneys often seem to oppose the program from the outset and put up road blocks more than helping to find solutions.
- The University does not always recognize the extensive faculty workload which the projects require by offering additional release time or assigning faculty collaborators.

EXTERNAL PHILOSOPHICAL DIFFICULTIES:

- Contractors do not understand the educational value of our projects as evidenced by their unwillingness to tolerate and subsidize the inefficiencies of building innovative structures with students.
- Contractors have a different philosophical mindset that stresses efficiencies and habit over innovation.

- Architects, students and faculty alike need to show greater respect for the experience and craft of builders.
- Communication is hampered by these different mindsets, habits, and assumptions. Therefore expectations and responsibilities are often unclear even when contract documents exist.
- The housing market does not adequately value contemporary sustainable design as evidenced by the lack of its availability and low appraisal values.

SOLUTIONS

The solutions listed here were developed through discussions with students, fellow faculty, homeowners, and other stakeholders in the Neighborhood Infill Housing Program. One ingredient in short supply comes up again and again when assessing the long-term sustainability and viability of the program: **TIME**.

Students and homeowners alike recommend that the cycle for each home be extended to two full years. A two year cycle would allow the first fall semester for schematic design, the first spring semester for design development, the first summer for construction documents, and the second fall, spring, and summer for construction. Additionally, more time in studio could be devoted to property acquisition, marketing, and real estate sales. Obviously the downside of this extended cycle is that the same group of students would probably not be able to stay with the project in their curriculum through the entire two years. However, the phases they were involved in would be more thoroughly researched and experienced. A new mantra for this approach might be called "unhurried building."

With regard to faculty and student overloads, lengthening the projects may also provide relief. Or if a year break was taken between projects this would also allow time for recovery and reflection. The pitfalls may be the loss of momentum and reduction of efficiencies gleaned through fast repetition. As another relief measure, additional faculty could be added to teach the program. However, this is problematic due to tenure and promotion policies which often preference individual research agendas.

Contractor difficulties could be reduced through self-contracting by the university or another internal partner (IE Tulane's URBANbuild).[23] In this way, the contractor would be a known quantity eliminating potential conflicts. Obviously having an internal contractor places greater liability on the university. Another solution would be to remove the Building Institute completely from under the wing of the university as its own not-for-profit thus streamlining the process (IE Kansas' Studio 804).[24] However, these more insulated models do not allow students to participate in true integrated project delivery with multiple stakeholders.

Finally, limiting the number of new designs so that prototypes would be refined and perfected over several years, instead of reinventing new designs and typologies every year, would result in greater stability and less risk. Or designing larger, multiyear projects such as multi-family live-work developments or even tiny-home villages, would result in enhanced efficiencies and economies.

CONCLUSION

For the profession, Design-Build as a project delivery system is growing and academic programs can provide a proving ground for optimizing and expanding this system. The community service component of EDB sets an example for the profession by better educating the underserved public as to the importance of design. And through Design-Build, designers sustain the design process during construction and introduce craft at every level. Value-added

ENDNOTES

1 The Free Dictionary website, http://www.thefree-dictionary.com/shrewd, s.v. "shrewd," accessed April 30, 2015.

2 Andrea Oppenheimer Dean and Timothy Hursley, Rural Studio: Samuel Mockbee and an Architecture of Decency. (New York, Princeton Architectural Press, 2002.)

3 Association of Collegiate School's of Architecture website, http://www.naab.org/architecture_programs/home and Author's own research/survey: Gjertson, W. Geoff. "A House Divided: Challenges for Design-Build Programs in Architecture Schools." Local Identities Global Challenges: 2011 ACSA Fall Conference, Houston. Edited by Ikhlas Sabouni, and Jorge Vanegas, ed. (2012): 23-35.

4 Juhani Pallasmaa, Architecture and Human Nature: A Call for a Sustainable Metaphor. In Bryan MacKay-Lyons, Edited by Robert McCarter's, Local Architecture. (New York, Princeton Architectural Press, 2015, p. 38.)

5 The cost of the homes was $111, $113, and $115/sf respectively- refer final illustration- comparison chart. None of the homes received actual LEED or Green Building certifications due to lack of funding and time to complete the process.

6 Some of these accolades include several blind peer-reviewed papers/presentations, the Independent Weekly's INDesign Awards for each of the three homes, a Freetown-Port Rico Neighborhood Community Pride Award, and numerous periodical articles praising the program in local and regional press.

7 W. Geoff Gjertson, Generating Hope: Stories of the BeauSoleil Louisiana Solar Home. (Lafayette, LA, UL Press, 2014.)

8 Building Institute website, http://ulbuildinginstitute.com/about-us/, accessed April 30, 2015.

9 A majority of all Building Institute funding comes from outside sources.

10 The Building Institute is Co-Directed by Professors W. Geoff Gjertson, AIA and Hector LaSala.

11 Lafayette Public Trust Financing Authority website, http://www.lptfa.org/about-us/, accessed April 30, 2015.

12 None of the three homes generated a profit.

13 Graham Goodyear, email to author, April 27, 2015.

14 Jake Grandon, email to author, April 26, 2015.

15 Nicholas Clesi, email to author, April 29, 2015.

16 Jake Grandon, "Travel/Green Building: Young Architects Forum Connection," November 2012. YAF PDF, p. 63, http://www.aia.org/aiaucmp/groups/ek_members/documents/pdf/aiab096572.pdf, accessed April 30, 2015.

17 Edutopia website, http://www.edutopia.org/project-based-learning, accessed April 30, 2015.

18 W. Geoff Gjertson and Christopher D. Trumble, “Design-Build Gone South,” Proceeding of the Fall ACSA Conference, WORKING OUT: thinking while building, 2014, p. 199.

19 Catherine Landers, Elizabeth Brooks, and Kirk Warner, interview by author, Lafayette, LA, June 14, 2013.

20 Ibid.

21 Stephen Verderber, “Territories of Educational Design-Build: Toward and Evidence-based Discourse,” Proceeding of the Fall ACSA Conference, WORKING OUT: thinking while building, 2014, p. 180.

22 Although the author received some additional compensation for project management it was well below minimum wage (3,000 hours of additional work compensated by $6,000-8,000 per project= $2.33 per hour).

23 Urbanbuild website, http://tulaneurbanbuild.com/index2.php#/home/, accessed April 30, 2015.

24 Studio 804 website, http://www.studio804.com/, accessed April 30, 2015.

design like custom furniture and custom details connect the architecture to the homebuyers and ultimately help “make the sale.” According to Catherine Landers, the fact that the “student’s hands were invested” in the project convinced her to buy the NEXThouse.

The profession can also learn from the Building Institute’s shrewd design process. Penetrating research is performed. Students carefully listen to potential clients. Conclusions are shared, tested, and documented. A variety of design schemes are explored individually. Then as an integrated team, a democratic design constitution is established and a final design is developed. This non-hierarchical process results in better collaboration and team member ownership, AND ultimately better design.

EDB programs, like the Building Institute, teach architects to be proactive and initiate their own projects. As a profession we cannot wait for the public, the market, or developers to ask for better design, we have to set an example by becoming agents of change. EDB programs are necessary for the profession’s own survival through better prepared future architects and therefore it is hoped that architecture firms will make greater investments of time and money in their local universities.

For the academy, the risk of losing programs like the Neighborhood Infill Program should prompt university administrations to make a larger and more thorough commitment to EDB. Faculty and students have to be more patient and content with incremental project development and willingness to accept lack of full-ownership of projects from year to year. Program accreditation should require Design-Build programs to meet additional criteria and NCARB should allow greater IDP experience hours from EDB for interns/students.

The subtitle of this paper, “unhurried building” is intended to be a rallying cry for EDB and professional practice. This “build-at-any-cost” mentality, as Verderber calls it, has to be resisted. Unhurried building is an attempt to codify the methodology of building with quality and sustainability as primary goals. Unhurried building does not mean that sustainability is not urgently needed but instead that we must conduct careful observation, planning, and construction to reach these goals. Unhurried building also reflects the mindset that the owner, architect, contractor and community must have during the process. Our agenda must be directed towards long-term goals not short-term gains. On a micro-level, unhurried building calls for a new paradigm of design research, construction documentation, supply-chain control, and building craft. When we hurry these processes we lose quality BUT more importantly we lose sight of our most critical responsibility- the health, safety, and welfare of the humans, animals, plants, and environment of our planet.

BeauSoleil FAMILY TREE FRONT	DATE	DESIGN DURATION	CONSTRUCTION DURATION	SIZE	ACTUAL COST W/O LAND	COST PER SF	STUDENT VS. CONTRACTED LABOR OR OTHER VOLUNTEERS	SUSTAINABILITY STANDARD	NUMBER OF STUDENTS
	2007 to 2009	330 Days	330 Days	800sf (1,500 sf decks/ ramps)	$300 K ($150K for production model)	$375/sf	90% vs. 10%	L.E.E.D. Platinum	8 officers 200 other students
 EVENThouse	2010 to 2012	250 Days	315 Days	1350 sf (580 sf porch)	$155 K	$115/sf	50% vs. 50%	National Green Building Standard Silver	3 officers 10 other students
 NEXThouse	2011 to 2012	240 Days	215 Days	1309 sf (418 sf porch)	$145 K	$111/sf	60% vs. 40%	National Green Building Standard Silver	7 officers 20 other students
 COURhouse	2012 to 2014	260 Days	290 Days	1508 sf (600 sf porch/ court)	$170 K	$113/sf	55% vs. 45%	L.E.E.D. Silver	6 officers 20 other students

5

Figure 5: Comparison Chart – Graphics by Megan Barra

The Urban Studio

A strategic alliance between Academia and Practice has been established in downtown Chicago. This unique collaboration between the University of Illinois Urbana-Champaign and VOA Associates Incorporated has yielded a new program: The Urban Studio of the University of Illinois Urbana Champaign.

KEVIN HINDERS
University of Illinois Urbana Champaign

INTRODUCTION

This collaboration has resulted in more meaningful projects and a more significant experience for both students and professionals compared to traditional studio approaches. With our recent success in mind, we are working to further strengthen our interactions to the mutual benefit of the University of Illinois School of Architecture and VOA. The opportunities are as endless as the energy, talent and ideas of our participants. In this paper, we will document how this program came to be, its current successes and challenges, and some of our exciting ideas for the future.

BACKGROUND

Founded in 1969, the global architecture, planning and interior design firm VOA Associates Incorporated believes in a collaborative design approach in its practice. VOA continually seeks out opportunities to interact with and contribute to the community, and academia in particular. VOA architects are currently engaged with academic practice at a number of institutions nationwide and in Venice, Italy. A global firm, VOA has offices in Beijing, Chicago, Highland Indiana, Los Angeles, New York, Orlando, Shanghai, São Paulo and Washington, D.C. VOA considers itself a multinational firm that provides the personal attention of a boutique studio. VOA engages in a collaborative design process. Immersing ourselves in each client's culture, we create spaces that tell a meaningful story about the people who bring them to life.

INCEPTION

For a number of years, the ISoA had been interested in launching a studio in Chicago which sought to explore urban design problems in the city. In the summer of 2013 the faculty of the ISoA and members of the City of Chicago mayor's office agreed to explore the mutual benefits that could arise from student/faculty participation on city projects. Associate Professor & Architect, Urbanism Program Chair and The Chicago Studio Coordinator, Kevin Hinders then made inquiries through the City of Chicago about finding a space for a new Urban Studio program in Chicago. He was shown several spaces, but found none that satisfied ISoA requirements.

1

Figure 1: Urban Studio students, 2014

STUDIO SPACE

VOA CEO and Chairman Michael Toolis, AIA, LEED AP became aware of the university's search for studio space in Chicago. He immediately thought of the portion of VOA's own space on the 13th floor of its offices in the historic 224 S Michigan building, the Santa Fe Building. Toolis met with Hinders and they toured the space. Toolis, an alumnus of the Architecture program at the University of Illinois himself, felt strongly that hosting students from the program in VOA's office space would benefit both VOA and the Urban Studio program. An agreement was reached for the Urban Studio to use a portion of the available space. VOA hosted the Urban Studio beginning in the Fall 2014 semester and agreed to a 5 year commitment.

Due to subleasing and time constraints, the VOA space on the 13th floor was unavailable for the first semester's investigation in the fall of 2014. Instead VOA hosted studio and classes for the Chicago Studio in their space on the 14th floor. This initial studio was afforded unique opportunities to interact with VOA employees. Since that time the designated space has been built out which affords a healthy interaction with VOA and other professionals in the Chicago area.

STUDENTS, SPACE AND PARTNERSHIPS

Urban Studio students are pursuing post-graduate degrees in architecture from the ISoA, . For the Urban Studio, they relocate to Chicago for one semester. Students live in diverse and lively parts of the city such as Lakeview and Wrigleyville. Some students choose to commute from their homes. While here, they spend their weekdays in the studio space itself, on tours and exploring the city. It's an immersive experience in designing for a modern city. Typically, the Urban Studio hosts 12-14 students per semester.

Not only does VOA provide the physical space for the program, but they provide professional expertise and informal consulting throughout the semester. Initially VOA's Melissa Ogden served as the primary liaison to the program. Since January, 2015, VOA's Shannon Piatek has served as VOA's primary point of contact to the program. VOA facilitates significant professional-student interaction in the form of reviews, informal critiques of projects and portfolios, charrettes of VOA's professional projects, lunch time Q&As, Pecha Kuchas and industry lunch and learns. Sharing space and interacting informally is powerful for both students and employees. The experience makes VOA's practice richer and allows VOA to witness firsthand the talent and trends emerging from our universities. It gives emerging professionals opportunities for exposure to our diverse profession.

2

Partnerships with the City of Chicago Mayor's Office and the Chicago Department of Planning and Development and the participation of numerous architecture firms in student visits and critiques make the Urban Studio possible. Additional firms involved in the first semesters include Solomon Cordwell and Benz, Holabird and Root, Booth Hansen, Gensler, Studio GC, Legat Associates, Nagle Hartray Architecture, SOM, Klein and Hoffman, Perkins + Will, Adrian Smith + Gordon Gill Architecture, Ross Barney Architects, Studio Gang and Goettsch Partners.

STUDIO PROJECT AS COLLABORATION MECHANISM AND VEHICLE FOR LEARNING

The Urban Studio is designed to align with the curriculum of the Illinois School of Architecture.

Students in the Urban Studio participate in three to four courses of study during their semester in the city: Experience the Urban Space, Experience the Architecture and Experience the Firms.

1. Experience the Urban Space: Project Development

The inaugural student project, Fall 2014, involved the investigation of a 200-acre site in close proximity to the Illinois Medical District and Fulton Market Innovation District, a site that includes the United Center and the soon to be completed new Malcom X Community College. The Urban Studio developed an urban design strategy/proposal for the area which sought to harmonize with the existing structures of the city and anticipate the future needs of residents and visitors while providing a new neighborhood quality which has been sacrificed by social and economic factors over the past fifty years.

The Spring 2015 Urban Studio group is examining transit oriented development for Chicago's Albany Park neighborhood. The city is looking for an innovative ways to promote development as well as the use of public transit. One of America's most diverse neighborhoods, Albany Park suffers from acute traffic congestion. Two teams of students spent the first half of the semester studying the demographics, history, architecture, culture and transport issues in the neighborhood and developing master plans for redevelopment. The second half of the semester had student teams developing detailed designs for new architecture in the area to support a smart transit-oriented development program.

The most significant advantage of the new program shines through in this project development. The Urban Studio students are able to experience and study the sites and populations related to these projects firsthand. "It's nice that the site is right here, we can just commute down," says one student regarding the Albany Park project.

Figure 2: Urban Studio students learn from visiting industry professionals


3

Student projects also benefit from the feedback on projects in progress from professionals working in architecture, development and planning. The Urban Studio regularly welcomes representatives from VOA and other major architecture firms for on-the-boards presentations and desk critiques of student projects in progress. In the studio space, students can show boards of research, planning and design and receive detailed feedback in person. Professionals offer their honest critiques of the concepts and presentation in this informal setting.

Students have noted that this feedback is invaluable and of a different quality than what they receive from peers or instructors while studying in Urbana.

Embedded in a studio on the 13th floor or VOA's Chicago offices, students of the Urban Studio have a close-up perspective on how a global design firm operates every day. Students participating in the studio can informally utilize professional architects and designers of VOA as a sounding board for their design concepts and studio projects. Students can get advice on job hunting in the field as well as seeing how important a cultural fit can be between architect and firm.

2. Experience the Architecture: Tours and exploration

In the fall semester, two seminars directly engaged the city as place. An Urban Morphology course offered insights into the typologies used in the Chicago block structure and the variety of urban conditions and responses throughout the city. In an Urban Phenomenology Seminar taught by Professor Brian Hammersley directly engaged the places in the city that give greater haptic experience to citizens and visitors in the city. This semester, under the direction of Professor Joy Malnar, students each week visit various noteworthy (often new and contemporary) architectural projects in Chicago (The Poetry Foundation at 61 W Superior St, EnV at 161 W Kinzie, Coast at 345 E Wacker, Virgin Hotel at 203 N Wabash to name a few). Additionally, students tell us that they use their free time to explore the city's neighborhoods and restaurants, gaining an understanding of Chicago's urban fabric as residents. Student feedback inspired to see close-up the historic and recent examples of architecture which they've studied in school. Students are also given the opportunity to volunteer during to the Chicago Architecture Foundation's Open House Chicago event. In recognition of their time, the CAF offers the participating students free tickets for their architectural tours.

Figure 3: Urban Studio students receive feedback on project work from VOA architects in regular informal critiques.

4

3. Experience the Firms: Office visits and critiques

On a designated day each week, Urban Studio students visit and tour the offices of major global architecture firms. The firms previously listed hosted students and faculty with the expressed questions: What are your firms ideals? What methods does the firm use to deliver on these ideals to both the client and the general public? These two questions formed the basis for both the firm's presentation and, we are told by the participating firms, a healthy bit of introspection. In addition, individuals from firms agreed to informally mentor a student from the studio. Some examples of mentoring included meeting for lunch, discussing portfolios and general knowledge sharing of Chicago and its activities. The weekly visit aspect of the program allows students to learn about these firms in greater detail—everything from their building type and market specialization to firm size, culture and mission. These firm visits give students unparalleled perspective on the profession as practiced in Chicago. Architects and designers from these firms are guests on open studio days, offering critiques and advice on project work. Visiting a variety of firms gives students experiences to which they can compare and contrast their VOA experience in terms of culture, projects and operations.

ALLIANCES AND SUPPORTERS

City of Chicago Mayor's Office and Department of Planning and Development

Urban Studio students meet with representatives from the City of Chicago Planning and Development department in developing their projects. Because of the groundwork set by ISoA's outreach, the ISoA Urbanism Program now undertakes urban design projects identified by the Mayor's Office as applied research investigations. Students work with the Chicago Department of Planning and Development representative Brad McConnell to identify the city's goals and objectives and then determine the strengths and weaknesses inherent in a location. Mr. McConnell serves as client for the semester while encouraging an investigation based upon the realities of land ownership and economics.

ROOSEVELT UNIVERSITY

The ISoA works with students and faculty from the Marshall Bennett Institute of Real Estate of Roosevelt University which assists the Urban Studio in gaining an understanding of the economic (pro forma, development strategies, etc.) realities of their design work while providing a worthwhile exercise for the Roosevelt Real Estate class. This academy-to-academy partnership is important for the Urban Studio program. In the future, it is expected that an iterative process will develop to assist students from both groups as they seek to broaden their education.

SIGNS OF SUCCESS… WITH ROOM TO GROW

Benefits Realized

VOA benefits from access to talent, ideas, energy of the next generation of architects.

- VOA has benefitted from a first look at the talent emerging from the School of Architecture, University of Illinois Urbana Champaign. This gives VOA a glimpse at trends, skills and interests of the next generation of architects entering the profession.
- VOA architects and designers were able to see and draw inspiration and best practice data from the example of how Urban Studio participants utilize research, technology, demographic data and resources in the City of Chicago and elsewhere in their projects.

Figure 4: Site visits bring students close-up perspective on Chicago's most recent architecture.

- VOA gets access to current thinking in academia on architecture and planning.
- The experience makes VOA's practice richer, creates opportunities for emerging professionals to understand the realities of our diverse profession and allows VOA to witness firsthand the talent and trends emerging from our universities.
- VOA has recently extended a full-time offer to Jake Eilermann as Intern Architect working in its hospitality group.
- Provide leadership positions for up and coming VOA staff
- Through critiques and stimulating discussions focused on design and design theory, VOA is able to reinforce the importance of design to its staff
- Students benefit from their access to the city, its architecture, project sites, professionals and their firms as well as numerous networking opportunities.
- Students have benefitted from the partnership in their exposure to Chicago, the profession and critiques from professionals.
- Students have been able to create their projects with input from the City of Chicago, architectural professionals, developers and community members. They have been able to observe urban locations for their projects over time and become familiar with their culture and demographics.
- Students have been able to observe the day-to-day life of VOA and learn about the culture and practice of other major architecture firms.
- Some students have been able to use the exposure to firms to take on part-time internships in concert with their Urban Studio studies.
- Studio participants gain access to major architecture firms and relevant professional industries in Chicago.
- Students gain an understanding of the types of firms (culture, size, project focus) they wish to work for.
- Students lay the foundation for professional and personal relationships that will continue throughout their careers.

STUDENT QUOTES:

On the Studio Experience:

> "I learned a ton in this studio. Being in the city provided tremendous opportunity for learning from examples and from advice (both in and out of reviews) from firms. Working with the city and working on a realistic Chicago Project is a huge plus for starting to work and finding a job... Professor did an excellent job of simultaneously teaching urban design so we felt confident in our solution."

> "This studio has been by far the most valuable since it provided lots of information that would be used in every course.".

On the Professional Development Experience:

> "This course is AWESOME! Worth running the Chicago Program for this alone. As long as the student has the desire, it is invaluable as a networking tool. Extremely useful to understand what the firms are about before I start applying for jobs. Mentorship is also very worthwhile."

> "People here want to help young professionals. The networking aspect is great."

> "I like the architectural tours of buildings. And in visiting firms, we can get into the firm and listen to their values."

5

"Being at VOA has given me a better idea of where I want to be after I graduate. Also, it's a really nice place."

THE FUTURE OF COLLABORATION

Now that we have significant informal collaboration, should we look at pushing this even further? With experience we have begun to look at aspects of the program that create opportunities for closer collaboration and a fuller experience for students. We are optimistic and enthusiastic about the potential for growth and integration. The VOA Urban Studio of the University of Illinois Urbana Champaign will continue to evolve and develop. Several students have expressed interest to further push the integrated experience within the Urban Studio and VOA. Others have expressed a desire for more capability within the studio space itself.

Below, we have noted some of the most significant adjustments and additions we have outlined for the program and the timeline for implementing them.

BUILD COLLABORATION INTO STRUCTURED SCHEDULE

One idea is to formalizing weekly or biweekly interaction. This will help to integrate the more timid students while expanding the greater support network for them within VOA. We plan to implement this in the Fall 2015 studio.

MENTOR/BUDDY SYSTEM

The Urban Studio program will connect students with VOA employees in a more formal way as buddies or mentors. We plan to implement this in the Fall 2015 studio.

PROJECT INCUBATOR

The Urban Studio will be used as an incubator on certain project types or projects experimenting with a new process. This will allow us to further explore the benefits of collocation. The studio will function as a true project team to either work on a real building project or work on a competition project. We plan to implement this as opportunities arise in Spring 2016. Potential benefits could include: revenue generation (or other in kind services) for the

Figure 5: With firm visits, Urban Studio students gain valuable perspective on careers in architecture.

University; if match with the right project this could be very beneficial for client at no or low cost; reinforce VOA culture of design and collaboration.

RESEARCH AND DEVELOPMENT LABORATORY

The Urban Studio could be used as a laboratory for experimental design research. Students and VOA could collaborate on conceptual design projects investigating the frontier of architecture and design. These designs would have educational and inspirational value for participants and great value in marketing and promoting both the firm and the Urban Studio.

CONTENT CREATION/MARKETING/DOCUMENTATION

Efforts have been undertaken to document the Urban Studio in text, interviews, graphics and photography and produce publications (print and online) to publicize the program.

IN CONCLUSION

The Urban Studio established in downtown Chicago is a strategic alliance between academia and practice. In its first year, this collaborative alliance in the immersive environment of Chicago and the office of an architecture firm yielded more meaningful project work and a more significant overall experience for students than a typical classroom studio. It also provided beneficial insights and access to talent and ideas for the firm and visiting professionals. Acknowledging this initial success, however, there is much room for growth and improvement in the details and scope of the program. There are many further opportunities to explore for uniting and experimenting with this particular colocation. The experience gained in the first year of this alliance will be applied to refinements and new aspects of the program.

Greater integration between the Urban Studio and VOA itself will deepen the experience for both participants. VOA will have a chance to better understand the character of the next generation of architects emerging from the Illinois School of Architecture. And students will gain a fuller appreciation of VOA's collaborative design process and a better understanding of the profession as a whole. Casual interaction and chance encounters are known to enhance the educational experience and further research. These chance interactions can be further promoted in future iterations of the Urban Studio program.

Under the leadership of the ISoA Urbanism Program, partners VOA Associates Incorporated, the City of Chicago Mayor's Office and Department of Planning and Development, Roosevelt University, participating firms and others have made the success of the Urban Studio possible. Thanks are due to these partners for making this innovative program possible.

The Columbia Building Intelligence Project

SCOTT MARBLE
Columbia University

In a short editorial in *Wired* Magazine just after the Crash of 2008, "The New Economy: More Startups, Fewer Giants, Infinite Opportunity", Chris Anderson suggested that what led up to the latest economic crash was not just another dip in the ebb and flow of reliable past economic cycles, but rather the last gasp of big-business models that were struggling to adapt to the new pace of change. They were being challenged by more agile, creative and innovative small firms with new models of scalability that would allow them to be competitive in large markets. This was not to say that large firms in all business sectors would cease to exist, but it did hint at a trend that has only accelerated since this claim was made 7 years ago; that much of the innovation and new ideas that are making big changes and disruptive shifts in how industries operate are being generated from small start-up firms. This is being largely facilitated by how these firms leverage digital communication technologies as the foundation of their business models along with their full embrace of a new social and cultural dynamic that in only 10 years has developed into an entirely new structure for the exchange of goods and services referred to as the Sharing Economy.

What does this mean for the architecture, engineering and construction (AEC) Industry and architectural education in particular? Architectural education used to be about preparing students to proceed with their internship upon graduation in preparation for professional registration and a stable job in an architectural firm. No more. There are indications that business as usual is getting short circuited by an impatient, eager, tech-savvy and network-minded generation who see alternative career tracks that are faster, more interesting, and capable of having a greater impact on industry. This new attitude is partly due to the memory of the recent economic slump and challenging job market that awaited recent graduates, but it is also the result of a hunch that this generation has that the future design and construction industry can and should be much different than it is now. The entrenched silo structure of the current AEC industry that continues to undermine the sharing of information and ideas that is the foundation of meaningful collaboration among architects, engineers, fabricators and contractors, seems alien to a new generation who grew up with the open information exchange of the internet and who see sharing as a natural way to gain knowledge and be productive.

THE COLUMBIA BUILDING INTELLIGENCE PROJECT (C BIP)

This hunch was at the core of the Columbia Building Intelligence Project (C BIP), which was launched at the Graduate School of Architecture, Planning and Preservation (GSAPP) at Columbia University in the fall of 2009. C BIP was initiated as a 3-year pilot research project designed to explore new forms of technology-enabled collaboration within and between the various sectors of the architecture, engineering, and construction (AEC) industry. The project grew out of an interest in using emerging digital design and communication technologies and the increasing trends toward more integrated forms of practice to address the entrenched adversarial atmosphere that has inhibited the progress of our industry for many years. In addition, C-BIP was based on the premise that changing the future of our industry depends on transforming the education of our future leaders, which begins with a renewed engagement between academia and industry.

C BIP was comprised of local and international Think Tanks and the C BIP Studio. The Think Tanks brought together leading industry experts including architects, engineers, builders, owners, fabricators, research scientists, software developers and educators in an open dialogue about current projects, working processes and research that form the most technologically progressive industry practices. Each year, one of Think Tanks was held in New York and was more directly related to the work of the C BIP Studio allowing an exchange of ideas between GSAPP students, faculty and the Think Tank participants. In response to the global dynamics of the AEC industry, the other Think Tanks took place in major regional centers around the world to better understand how the topics around design, technology and collaboration shift in different cultural and economic contexts. The Think Tanks uncovered key questions and issues that established a broad foundation to position and evolve the C BIP Studio.

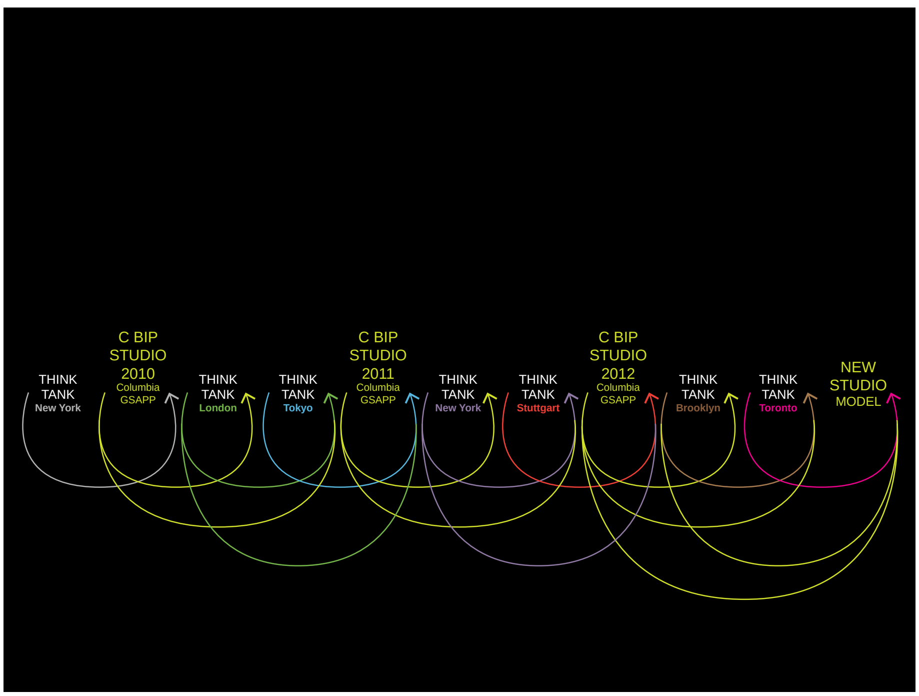

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Figure 1: C BIP Diagram

The C BIP Studio was the anchor of The Columbia Building Intelligence Project, which was conceived as a new studio model that responded to the increasing complexity of contemporary design problems. As an evolution of the typical studio model of 12 students working on individual projects and guided by a single instructor, the C BIP Studio was a highly integrated model where 36 students worked interactively on specific parts of a larger problem, guided by three critics and several technical consultants and guest advisers from industry who served as experts on key issues relating to the studio topic. The primary objective of this new structure was to encourage the sharing of information, the open exchange of ideas and a deep understanding among the students of the potential of collective teamwork. The students produced design work that was shared and combined through structured parametric modeling allowing the individual work of each student to contribute to the entire studio. The C BIP Studio took place in the fourth semester of the Master of Architecture Program when students transition from core to advanced studios. At this point in their education, students had enough background to make informed contributions to a team project while also having another year after completing C BIP to integrate their new findings into future work at the GSAPP.

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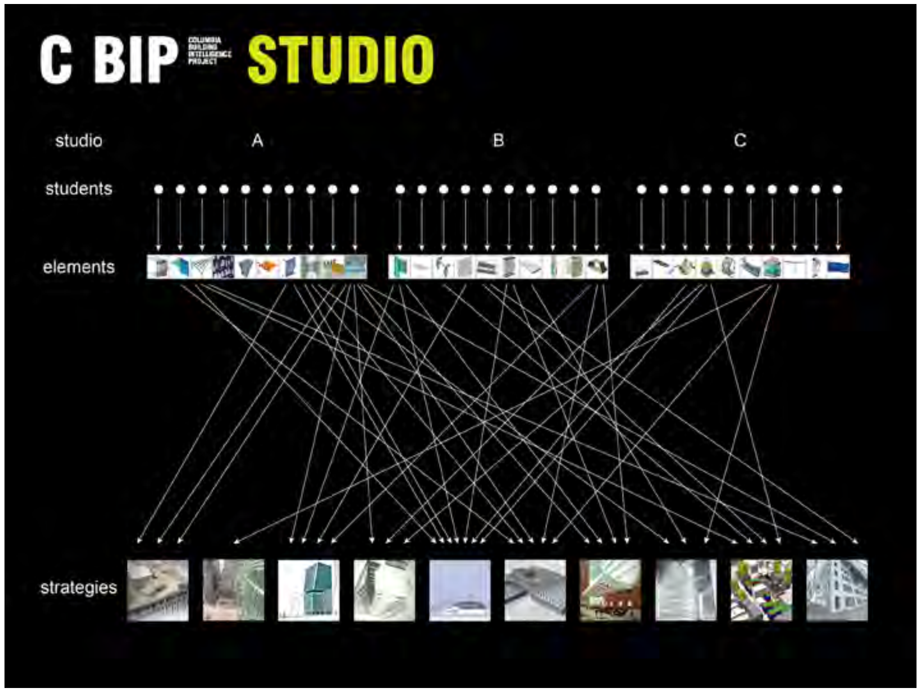

THE STATE OF INDUSTRY – THE CONTEXT FOR C BIP

The practice of architecture has always been about managing information. Architects produce drawings that coordinate the efforts of multiple constituents with the goal of producing buildings. However, the amount of relevant and available information that is useful for any given architectural project today has expanded faster than the development of integrated and synthetic working methods. The amount of expertise required to design, fabricate and construct a new building has lead to multidisciplinary teams that expand far beyond the traditional architect, engineer, and contractor model. This has simultaneously led to more collaboration between individual people, specialized teams, and a fragmentation of information that often inhibits the full benefits of a collective workflow. This is largely due to the lack of effective means to organize and coordinate the efforts of the multiple team members. While this is certainly a *logistics* issue, it is also a *design* issue in that any organizational system has inherent biases that either support or obstruct the potential of creative work.

With the availability of ubiquitous digital communication technologies, the rapid transformation of industry through these technologies, and a new entrepreneurial spirit among a younger generation, architects are now able to leverage their position so that they have the potential to *design the organization of a project*—to creatively and strategically assemble new alliances and relationships among owners, clients, builders, fabricators, consultants,

Figure 2: C BIP Workflow

etc. that lay the groundwork for innovative architecture. The C BIP Studio addressed this new working environment with the goal of preparing the next generation of architects to lead in the development of new modes of practice.

Acknowledging that industry is already moving toward a restructuring with new developments like Building Information Modeling (BIM) and Integrated Project Delivery (IPD), which promise to address many of the procedural inefficiencies in design and construction, C-BIP attempted to build on this restructuring while also critically addressing some of the difficult questions beginning to emerge for architects. For example, what is the relationship between BIM and design? At what point does the degree of integration that is the basis of both BIM and IPD become a deterrent for design, innovation, and risk taking (which goes hand in hand with innovation)? Is the degree of integration inversely proportionate to the degree of flexibility for more open-ended design? Are BIM and IPD only for managing workflow or can they evolve to support more effective design methodologies?

One aspect of the studio methodology borrowed from the concepts of *collective intelligence* and how it might be applied to architecture. As individual projects evolve to include more and more information, as well as more and more stakeholders, how might diverse and decentralized groups make intelligent design decisions? In architecture, is it possible to leverage "the wisdom of crowds," as theorized by business writer James Surowiecki?[1] Is there a way for design teams to take advantage of "crowd sourcing," the contribution of many distributed users toward a collective product?

Another aspect explored how *open source*—a design method pioneered for software development—might be reformulated for architectural design and how multiple independent parties might build successive versions of a part toward the goal of a single deliverable.[2] Could modules of buildings and 3D files be "checked out," revised, and "checked in" by different architects, fabricators, and contractors over time durations that exceed a single project? How would discrepancies between versions be handled? If complex building parts could be designed, documented, and released into a broad architectural community, how would intellectual property be handled? Might an open source model start to change the one-off nature of buildings and reduce inefficiencies in the construction industry?

The C BIP Studio also explored how cooperation and sharing could change the process of design to realign the motivations and incentives that drive design decisions.[3] Shared risk, shared reward is a cooperative structure at the core of Integrated Project Delivery (IPD) intended to align the priorities between design teams, contractors and owners around financial incentives. This structure is less beneficial for architects due to the value of their services, in financial terms, in relation to overall project costs. What other value structures could encourage people to move towards collaborative work? Can the silo structure that defines current practice be overcome in a highly litigious working environment? If so, how can the next generation accomplish this and put legal structures at the service of design instead of vise versa. Can the next generation transfer the deeply rooted culture of sharing that defines their daily social life into a sustainable business model for design?

The C BIP Studio engaged these more speculative questions backed with an understanding of the current state of industry to develop new design workflows that might contribute to meaningful change to the practice of architecture and its future position within the AEC industry.

ENERGY + ADAPTATION, THE C BIP PROGRAM

Cities around the world have begun developing ambitious programs with specific goals and timeframes to make tangible progress in addressing global climate change. As one example, PlaNYC was initiated in 2007 with the target of reducing carbon-dioxide emissions in New

York City by 30% by the year 2030. Because of the density of NYC, buildings make up 75% of the city's overall carbon emissions. The advances made in high performance design and engineering will keep new buildings from compounding this problem. However, 85% of the buildings that will exist in NYC in the year 2030 already exist today so, as in most cities, the greater challenge is not the design of new buildings but how to adapt the existing building stock to current standards. This challenge was the program topic of research for the C BIP Studio.

As a systematic approach to addressing energy mitigation and in order to address the greatest number of low performing buildings in the city, representative building types were determined through an urban analysis using numerous relational data sets and parameters taken from the PlaNYC program. These parameters included buildings larger than 50,000 square feet (SF) and buildings built before 1990, the time period when energy performance became a more important design concern. This analysis resulted in six building types that collectively represented just over 37% of the total building SF in New York City, but more importantly, these 6 types represented 87% of the building SF of buildings within our targeted building profile. These types included glass towers, schools, lofts, mid-rise residential, high-rise residential and public housing. A representative building was chosen from each of these types as a case study site for the studio.

Much of the building adaptation work to address energy mitigation occurs with little or no architectural or urban effect – upgrading building systems, increased insulation on perimeter walls, window replacement, etc. Students were made aware of this but were also asked to explore how to leverage the resources that would be dedicated to this effort to design adaptation strategies that would affect the urban landscape. The following environmental metrics were used to direct this effort: increased daylighting, reduced heat gain or heat loss, quantity of water stored and re-used, change in vegetated area, electricity or solar heat generated, improved ventilation and reduction in construction waste.

DESIGN & RELEASE – THE C BIP STUDIO WORKFLOW

Unlike a typical studio in which students work alone and produce one-off designs, the C BIP Studio employed a *design-and-release* model based on sharing. Over the course of the semester, each student authored a building Element (addressing a building part) that would be combined with Elements authored by other students to create a building Strategy (addressing an entire building). A single student designed the Elements in the first phase of the semester and the Strategies were designed by a group of 3-5 students in the second phase. As the semester progressed, students would be simultaneously refining the design of their Elements while also working in a group to develop a Strategy.

For the design of their Elements and Strategies, students utilized design, analysis and production software currently used by the building industry for its most advanced projects. Taking advantage of the unique opportunities of academia, students explored BIM practices and parametric modeling techniques in novel and experimental ways to contribute to the broader research and development of new integrated and collaborative design workflows. The core software of the studio workflow was CATIA, a powerful parametric modeling platform originally developed for design and manufacturing in the aerospace industries by large distributed teams of engineers and now being used to design and construct complex architecture projects.

In addition to the 3 design critics, the teaching team consisted of several technical experts from local architecture, engineering and consulting firms who developed and managed the digital workflow for the studio. These outside consultants also brought industry expertise in other areas including architectural detailing, structural engineering, environmental engineering and software interoperability. Over the course of the semester, students became fluent in CATIA as the common platform for structuring the exchange of design ideas with others in the studio through shared parametric models. Students also learned to use SVN (a version-control system for managing and sharing current and past versions of files), SBA (an arbitration system for resolving conflicts in design goals), along with multiple methods for building simulation (including finite element analysis, computational fluid dynamics, and environmental analysis) for evaluating the performance of design iterations. By utilizing these new advanced modeling tools and structured design workflows students were able to create robust, adaptive parametric models that set the foundation for the most important objective of the C BIP studio - sharing design intelligence

PHASE 1: ELEMENTS

Elements were designed by each student in CATIA in response to their research on energy use and the particular NYC building type selected as a site. In this first phase, Elements were designed as prototypical based on generic building conditions with maximum flexibility to adapt to more specific building conditions during the Strategy phase. The studio took two approaches toward energy-related building adaptation: the mitigation of energy use and the harvesting of energy. To focus the work students chose one of three building conditions to address: facades, roofs, and courtyards. Beginning with the design of generic building components, the students adapted their designs to each other's and to a series of selected buildings, urban conditions, infrastructures, and scales. The goal was to invent architectural solutions to energy mitigation and harvesting in existing buildings that were at once speculative, experimental, innovative and technically feasible. [IMAGE 3: SAMPLE ELEMENT]

As parametric models, Elements were structured with specific inputs and outputs that were an essential part of the author's design intent. Inputs had to give users sufficient flexibility to explore many design options without being too open-ended. Outputs had to provide users with useful information to be able to assess results. Outputs consisted of both geometry (visual images that architects typically use to qualitatively evaluate results) and numbers (metrics that give quantitative aspects of the results).

In anticipation of phase 2 where Elements would be combined to form integrated Strategies, students (as Element authors) were asked to exchange early versions of their Element design with at least 2 other students (Element users) to get feedback on usability and overall design capacity. Users were encouraged test the limits of the Elements to get unexpected outputs and even to "break" the Elements if possible. This step proved valuable in making sure the Elements were designed to be robust and in providing authors with new ideas about how to expand the functionality of their designs. As part of the exchange, students were also required to combine two Elements together where the numeric outputs from one served as the inputs to another. This was the initial step in understanding how Elements could link together to form a Strategy. It also emphasized the point that by definition, Elements should be conceived as "incomplete" and reliant upon other Elements to realize greater design potential.

At the conclusion of this phase, v1 Elements were packaged and uploaded into an Element Library for use in the next phase. These early versions became referred to as "low-res" and often emphasized the overall functionality to generate useful numeric outputs over fully developed geometry with the understanding that users would want more control over geometry and appearance. User guides were attached to each Element explaining the authors design intent and providing users with step-by-step instructions on using inputs and outputs.

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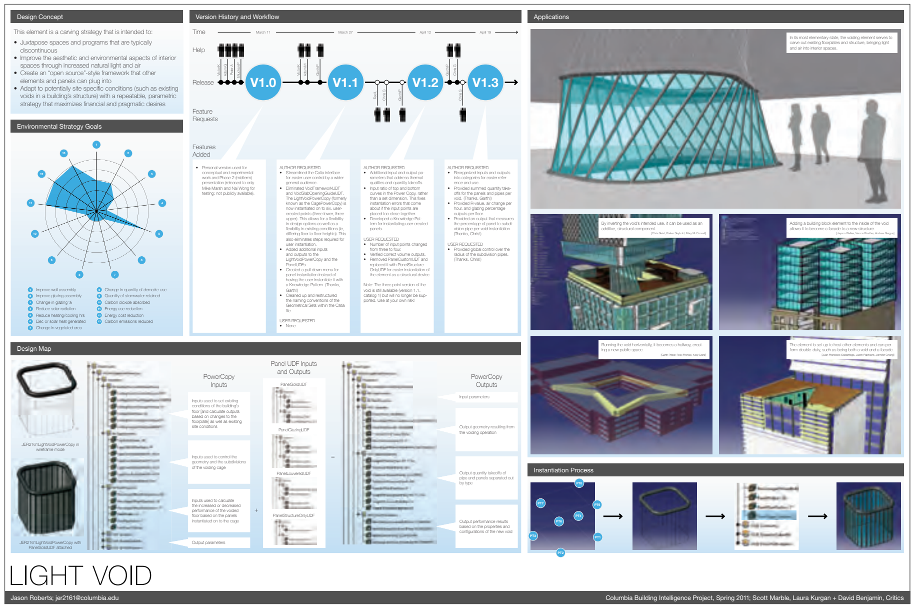

PHASE 2: STRATEGIES

In the second phase of the studio, students formed into small groups, selected a NYC building type based on research from PlaNYC as a "site" and began developing ideas for a building Strategy. As the student groups were developing concepts, they would search the Element Library for Elements that related to their design intent. As groups would start to test Elements on their sites, they would discover limitations in an Elements functionality that would require updates in order to develop their design. Two important rules of the studio structured this process – the first was that *updates to Elements could only be done by the original author*; the second was that *groups could not use an Element authored by one of its group members*. These rules greatly expanded the exchange of Elements and overall sharing of ideas as each student would be working with their own group to develop their Strategy while also working indirectly with several other groups who had selected their Elements for use in the design of their group's Strategy. Following techniques of open source software development, student groups were able to experiment with and suggest specific updates

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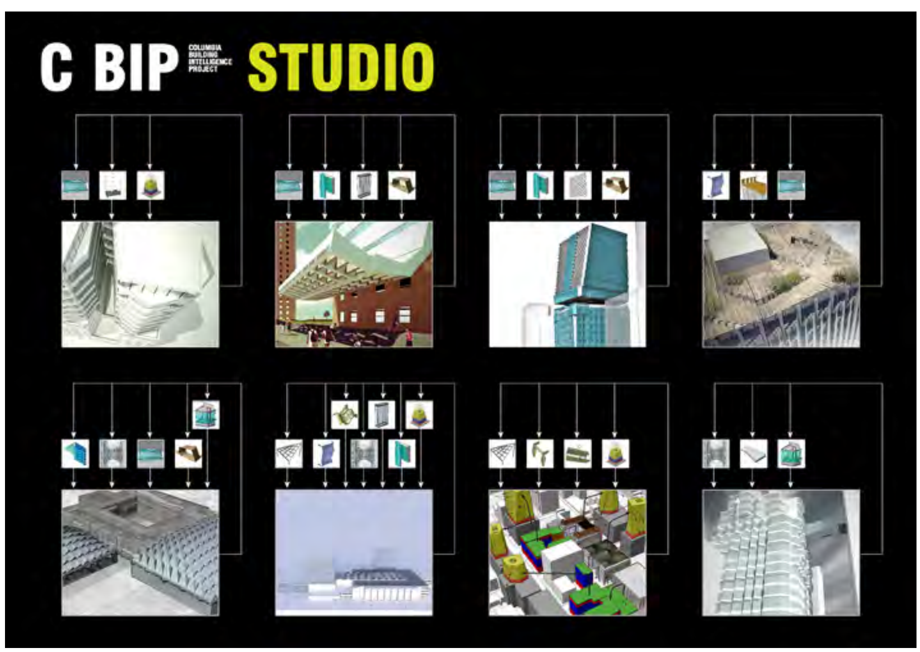


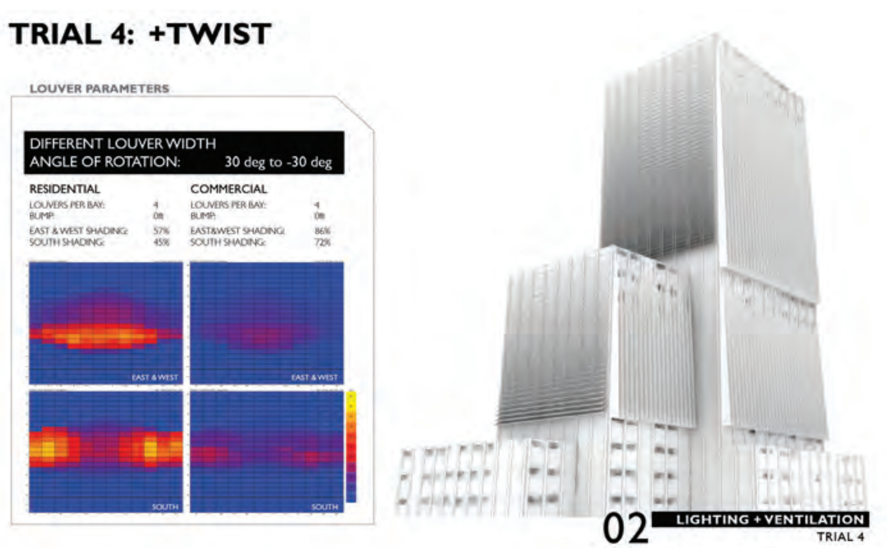
Figure 3: Sample Element, Juan Francisco Saldarriaga

Figure 4: Jason Roberts

to any Element they might want to use in their Strategy but be required to follow mutually agreeable protocols in getting these updates executed.

The objective of designing Strategies instead of solutions was to encourage students to exploit the parametric capacity of their work so they could be applied to the greatest number of buildings, within their chosen type. For instance, the inputs for the Strategies were variable and could adjust to the specific conditions of different buildings allowing the Strategies to be reusable beyond a single site. With this approach, a limited number of Strategies could be applied to the greatest number of buildings resulting in a more significant impact on the PlaNYC goal of a 30% reduction in carbon emissions by 2030.

The most successful Strategies were able to get multiple Elements linked together in a fully integrated model where the fewest number of inputs could generate the widest range of design outputs. These outputs were presented as dashboards that included visual images along with numeric and graphic readings of quantitative information about the design. For both Elements and Strategies, results were iterative meaning that there was no single solution but rather multiple iterations based on different inputs.



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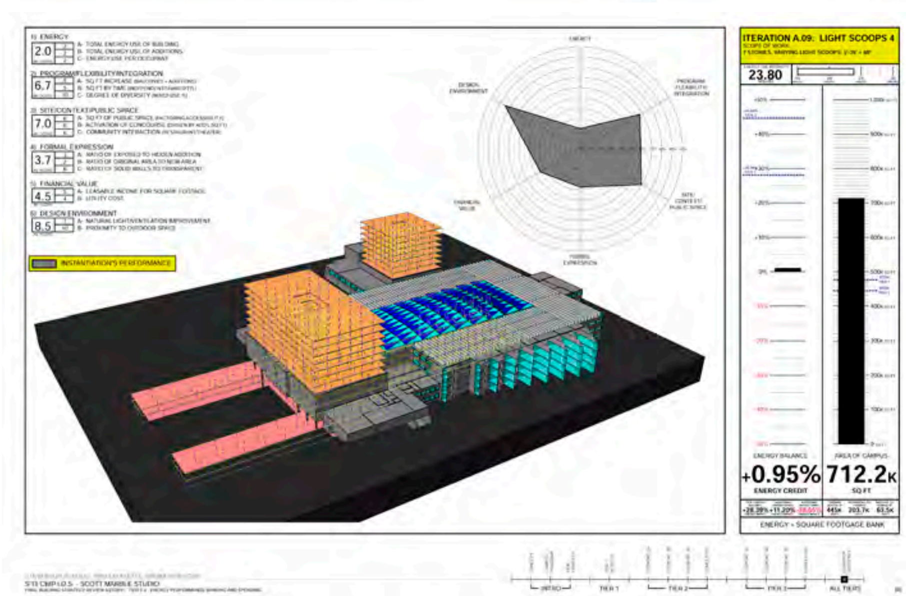

Figure 5: Sample Strategy, Ardeshir Aliaskari, Jennifer Chang, Justin Fabrikant, Juan Francisco Saldarriaga

Figure 6: Dashboard, Jason Roberts, Nai Wong, Michael Marsh, Michael Marvin

C BIP PROJECT CREDITS: C BIP STUDIO DIRECTOR: SCOTT MARBLE

Design Critics: Scott Marble, David Benjamin, Laura Kurgan, Janette Kim

Industry Consultants: Victor Keto, Gehry Technologies, *Software, Optimization*; Adam Modesitt, SHoP Architects, *Software*; Cory Brugger, Morphosis; *Software;* Neil Meredith, Gehry Technologies, *Software*; Alexandra Pollack, SOM, *Software*; Hashim Sulieman, SOM, *Software*; Neil Thelen, Front, *Software*; Emilie Hagan, Atelier 10, *Energy*; Madhev Munshi, Atelier 10, *Energy Modeling;* Stephen Mignogna, Atelier 10, *Energy Modeling;* Johathan Schumacher, Thorton Tomsetti, *Software, Interoperability;* John Cerone, SHoP Construction, *Software*

Student Teaching Assistants: Jacob Benyi, Caniel Nagy, Peter Adams, Adam Gerber, Julie Jira, Muchan Park, Alexis Burson, Chris Geist, Jason Roberts, Garth Priber, Jayson Walker, Joseph Brennan, Karl Bengzon, Christine Nasir, Mia Zinni

C BIP Think Tanks Chair: Phillip Anzalone

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The Columbia Building Intelligence Project was generously supported by Oldcastle BuildingEnvelope

Oldcastle BuildingEnvelope *Engineering your creativity*™

At the conclusion of the 3-year pilot period, the C BIP Library contained over 100 individual Building Elements and over a dozen integrated Building Strategies.

SHARING AS A NEW MODEL OF DESIGN STUDIO

The technical protocols of the C BIP Studio created a powerful incentive for students to understand the structure of collaborative work. Students quickly realized that *the success of their own work relied on the success of their peer's work.* This created a unique social dynamic that added unfamiliar factors into their typical design process. For instance, during the Strategy phase of the studio, students would have to manage their time and their aspirations between contributing to their own group Strategy and updating their Elements from feature requests from other Strategy groups. The incentive for focusing on the later was that if their Elements were being used by several groups, their impact on the total studio output would be greater as they would indirectly be part of several groups instead of just one. This was especially the case for students who had very popular Elements. On the other extreme, when an Element was not being used by any group, the author would have to decide whether to put more of their time into their group Strategy or try to revise their Element on their own to be more appealing to users. In general, Elements that were more formally generic and functionally robust were more popular among groups. Some of the most popular Elements over the 3-year period were those that were purely operations. For instance, one of the most popular Elements, *Light Void*, simply created slab cutouts in existing floor plates, which could be utilized by groups in multiple ways for different programs.

In the second and third year of the studio when students could choose Elements authored by students from previous years as well as those authored by their current studio mates, they tended to use Elements from their current studio. This reinforced the importance of face-to-face exchange when engaging in a creative process like design, even when everything is online. The previous year's Elements, however, did have a cumulative impact on subsequent studios in that students started to be more ambitious with the design of their Elements because they realized that they had to build upon past work and not repeat Elements that already existed in the Library. This awareness of the Elements from previous years indirectly encouraged better design.

CONCLUSION

Design studio is deeply entrenched in architectural education. Entire curricula revolve around the structure and content of studio and it is the cultural and creative anchor of architectural schools. It is a teaching model that is the envy of educators in its ability to be both structured and open-ended where students learn as much from each other as they do from an instructor. The challenge for educators is how to evolve studio so it not only stays current with, but stays ahead of the profession that it serves. Exploring the full potential of digital design and communication technology and how it can expand the design capacity of our students is one part of addressing this challenge. It is a missed opportunity to casually position digital technology as just tools. Technical skills and design skills are becoming intertwined as part of a complex workflow requiring a new mental agility among designers to move fluidly between qualitative and quantitative thinking. One does not enable the other but rather, they work in tandem.

The challenge for the profession of architecture is whether we will take a back seat in the development of these new workflows and remain on the receiving end of a professional infrastructure that will increasingly set the ground rules for how we practice or alternately whether we become proactive in the design of this infrastructure. This covers both the tools that we use to design and the organizational structure of our professional relationships. How this challenge is met will be determined by how architectural education engages with industry and how bold we are as educators in pursuing curricula that prepares students to lead in this long-overdue change.

ENDNOTES

1. Surowiecki, James. 2004. *The Wisdom of Crowds: why the many are smarter than the few and how collective wisdom shapes business, economies, societies, and nations.* New York: Doubleday, 2004.
2. Raymond, Eric S., 2001. *The Cathedral & the Bazaar*; O'Reilly Media
3. Axelrod, Robert, 1984. *The Evolution of Cooperation*; Basic Books, Inc.

Pedagogy of Practice

The complexity of practice is increasing...

ABSTRACT

The day-to-day practice of architecture must navigate within a system of contexts often replete with competing values dictated through external forces by clients and patrons to effectively execute the work. This requires the process of design and construction to respond to constant tactile adjustments made by the demands of clients, codes, budgets, etc. to address the landscape of contingency. Every project, decisions are made about quality of materials versus reality of budget and time constraints or owner-prescribed values and requirements versus site and building code constraints. Engaging these conflicts defines the profession of architecture.

So can architectural students confront these conflicts within their own education?

What is the role of professional practice in architectural curriculum?

Professional Practice curriculum plays an essential role in addressing conflict in the practice of architecture. The course introduces students to the comprehensive field of practice, existing within a broad range of social, organizational, economic and professional contexts. The course is typically taught as medium to large size lecture course, with little opportunity to critically engage the complexity they will be thrust into following graduation and limiting its effectiveness as an intersection between the academy and architectural practice.

The community design academic experience has become valued pedagogy within architectural curriculum. It provides students irreplaceable life lessons: real world decisions have consequences and create a thriving environment for architectural education where innovative solutions address normative problems. The scale and complexity of many community design projects result in a field of shifting priorities necessitating design agility. Effectively integrating these types of real-world projects into a professional practice course can better position the curriculum as a crossroads between architectural practice and academy.

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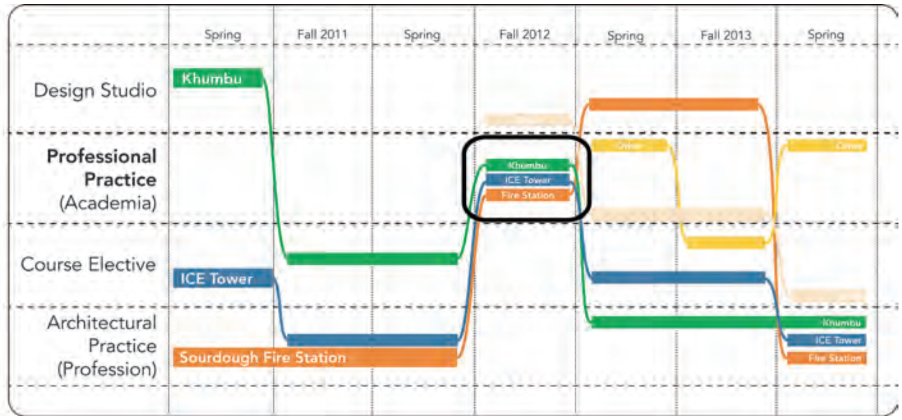

Figure 1: Diagram representing the timelines of three community design projects and how they were itegrated into the Professional Practice class

This paper will present a unique approach for the Professional Practice curriculum, which effectively integrated "productive conflict" from three community design projects. The School of Architecture is engaged in three to five community projects, at one stage or another, in a typical semester. The type of project, scope of work, and stage of development inform whether a design studio, topical elective, or Professional Practice is the appropriate educational/service context. Many times community projects begin in one context and shift platforms through their different phases. In all cases, projects integrate or are bridged to design professionals. For the Professional Practice work presented in this paper, students were immersed in the setting of an in-progress, project defining conflict. Each conflict defined a different point during the project timeline (Figure 1). They guided community discourse by creating and presenting alternative project approaches that moved the discussion along. This created an environment of deliberation that generated new perspectives, added to the flow of argument, and often revealed previously unconsidered issues and solutions. This emergent process benefited students by situating classroom knowledge in a dynamic environment of social complexity and political exigency. Ultimately, the projects operated as a type of joint venture and/or bridge with actual architectural/construction work completed outside the school of architecture.

INTRODUCTION

An AIA Foresight Report in 2013 on the changing context, business, and practice of architecture revealed that the complexity of practice is increasing. In the global economy, new markets are emerging. They are becoming economically powerful, requiring earlier and more thorough collaboration as the new norm. There is a need for evolving models of practice, embracing the short-term revolution of social, mobile and cloud-based technologies. Firm hierarchies are shifting; changing expectation of younger talent demand a "mentor up/ mentor down" approach of mutual benefit.

The role of the contemporary architect is multivalent, defined by social, cultural, political and financial constraints. Practice must navigate within a system of contexts often replete with competing values: quality of materials versus reality of budget; and time constraints or owner-prescribed values and requirements versus site and building code constraints. The new context inherently includes more diversity and consequently, increased conflict as varied values, interests and agendas come together. The traditional responses to complexity are to not confront the potential conflicts. Teams stigmatize 'conflict' in lieu of a 'common goal' philosophy. Resources are optimally distributed to meet everyone's needs leading to a culture of compromise but not necessarily fulfillment.

So what are the benefits of embracing the issue of conflict? Can practice begin to approach conflict as something of assets rather than a liability?.

Engaging these conflicts define the profession of architecture. Increased collaboration increases the possibility of conflict. This should give us pause and reassess a 'split the difference common-good strategy' in favor of mutually beneficial win-win opportunities. The specific contingencies that a conflict engages reveal meaningful issues and are a measure of social engagement that various design alternatives could have. Conflict seen as opportunistic and as a productive social concept is a positive and empowering interpretation of the real-world dynamic that can happen in architectural projects.

So can architectural students confront these conflicts within their own education?

Conflict is not an established area of engagement within architectural curriculum. Typical design projects are developed which minimize conflict to clearly reveal specific design objectives. However, in contrast to the traditional design studio community design projects are opportunities to engage the contingencies that confront many real design projects.

Community Design programs have been established in many architectural programs throughout the country. They engage community/university partnership approach with a range of community groups and non-profit organizations. These programs are popular for students and valuable to architectural curriculum because they build the capacity within a School of Architecture to define problems with an interdisciplinary lens, encompassing a broad spectrum of design challenges relying on a beneficial exchange of knowledge and resources in a context of partnership and reciprocity.

What is the role of professional practice in architectural curriculum?

Professional practice curriculum for NAAB accredited architectural programs should be a nexus between architectural education and practice. The course introduces students to the complex condition of contemporary architectural practice and varied roles and responsibilities of the architect. Often positioned at the back of the curriculum, it operates as a synthesis of integrated design for students to command the knowledge required to begin their career in the architectural field.

COMMUNITY DESIGN AS PROFESSIONAL PRACTICE

Professional practice education can benefit greatly from the integration of community design projects into the learning objectives. Through a participatory community design process, students learn how to tailor their talents and skills to existing contexts and client groups.   Students are immersed in the community and the reciprocity of people and place. This type of knowledge requires students to become active participants in the learning environment in their education experience rather than passive recipients. With community design projects, students engage a comprehensive material world. They discover the language of clients and craftsman as very different from their own. The scale and complexity of the projects is greater than students can complete on their own and requires them to engage collaboratively in the process, making it an irreplaceable life lesson: real world decisions have consequences and create a thriving environment for architectural education where innovative solutions address normative problems.

An opportunity was envisioned to merge the real-world challenges of community design project with the Professional Practice course at the School of Architecture at Montana State. The 2012 spring semester professional practice course was organized around three community design projects: The Sourdough Fire Department Fire Station (SFD); The Bozeman Ice Tower (ICE) and the Khumbu Climbing Center (KCC). The class was divided up into teams and assigned one of the following projects (each encompassing a different phase and unique conflict within the design-construction process). The team followed their project throughout the semester, learning about, engaging with, and completing tasks (assignments) that correlate with the project's respective phase. A collective knowledge approach was used: each team was required to give presentations to the other students in the class, explaining what they were working on and what they learned. The three projects covered during the semester emphasized the role of the architect as a systemic thinker and creative collaborator.

SOURDOUGH FIRE STATION: PRE-DESIGN PHASE)

Knowing how to build is a matter of science and technology, but knowing what to build is a question of morality, ethics, and aesthetic responsibility. The pre-design phase of a building project is about defining the problems one must ultimate solve. Project definition, program development, and developing design strategies for fundraising become some of the architects' responsibilities. However, in architectural design studios students are traditionally given the design problem to solve yet seldom given the opportunity to develop it.

The Sourdough Fire department is one of two fire stations in the Sourdough Fire District and one of five that form a consortium of emergency response units in the Bozeman, Montana area. The Sourdough volunteer fire station specifically serves a 15 square mile area encompassing approximately 5,000 residents in 1,400 homes and is developing rapidly. This increased resource projection in the district would have a significant effect on emergency response. Upgrading the Sourdough Volunteer Fire Department services would ensure the best in protection for responding to emergencies in the community.

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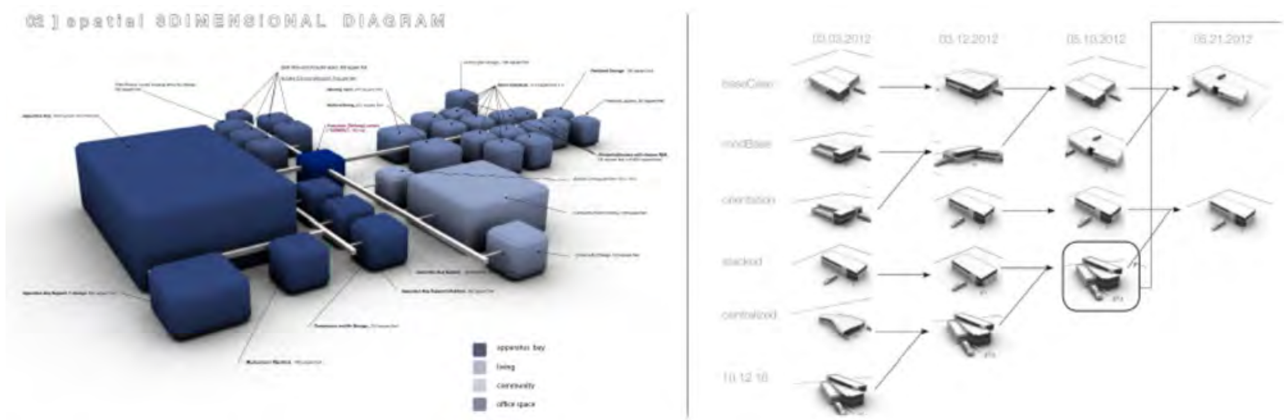


Despite the need for resource improvements for the district, the community had rejected two previous mill-levy votes in the previous 6 years. A community design project emerged from which to work with design students in the professional practice class to develop a new design proposal for another mill-levy vote.

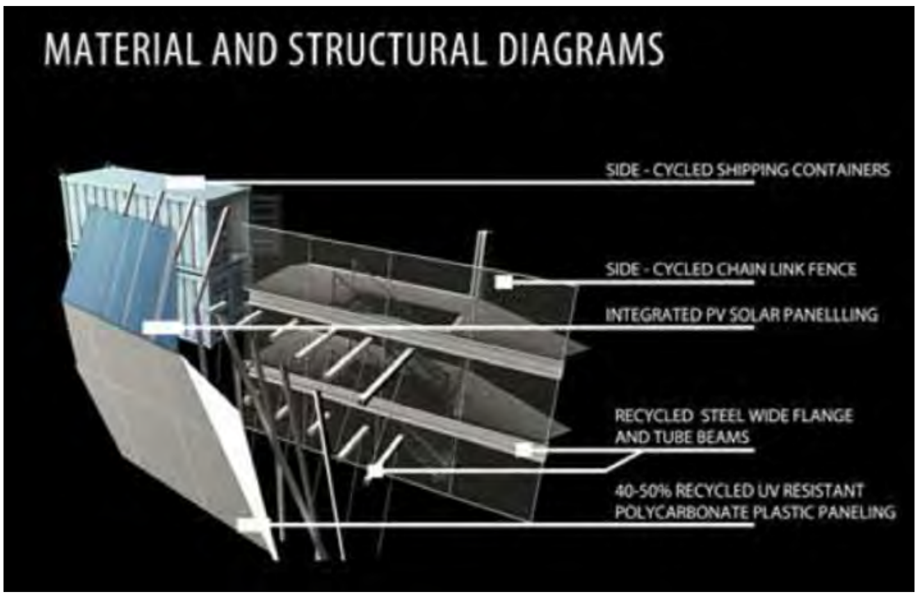
The Sourdough Volunteer Fire station project would serve as an opportunity for professional practice students to engage in the pre-design phase of a real-project. A successful approval by the voters in the up coming election was the real-world challenge. The pre-design phase completed by the students included project feasibility study, precedent research, and project programming for a new 10,000sf station. The design included a 4-truck apparatus bay, dormitory and living facility for fire fighters and large community/training room. The team of students completed a schematic design, including the site planning, and energy analysis. A key challenge for the pre-design was working with a defined budget, so students worked with a contractor on the cost estimate tracking the cost for the construction of the new station.

Figure 2: Programming Diagram (left) and 'Versioning" design process (right)

The schematic design phase used a 'versioning' strategy, which is a non-linear process where versions are created, and then interrogated on series of design and performance criteria, resulting in the emergence of new versions superior to the previous iteration (Figure 2). This process was critical to the concept of engaging conflict because it propagated a wide range of design scenarios. This process shifted discussion from 'building as product' to 'building as medium for performance'. Design factors used for analysis included building efficiency (function), truck access and maintenance, etc. Using Rhino and BIM software such as Revit, the iterative process began with a base case solution with additional iterations developed improving on the design. Ecotect analysis software was used to explore energy performance. This design strategy helped students to effectively communicate to the users design issues from which to compare and arrive at an optimal solution. The project was presented to the community and later approved by the voters in November of 2012.

THE BOZEMAN ICE TOWER (ICE): DESIGN DEVELOPMENT PHASE

The ICE project is an 85' high climbing tower to be constructed on the County Fairgrounds in Bozeman, MT, it is in the design development phase. The original schematic design is the winning scheme from a national design competition created and organized by the School



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of Architecture in collaboration with the Bozeman Ice Tower Foundation (BITF), a non-profit formed for the project. The formal concept of the tower is a triad of stacked shipping containers, an interior core of platforms, and a sub-framed skin for freestyle climbing (hand-holds and farmed ice in the winter). The skin, not developed in the competition entry, became the initial focus of development and documentation for the student team.

The "architect" for many projects is an assemblage of various experts: strategically selected, integrated and managed to meet the performance criteria of the project. Students researched potential team members through a comprehensive multi-disciplinary lens. They recognized that the design, to be successful, would need to function in a system of contexts: conceptually, as an inspiring activity; economically, as a component of a business plan; structurally; and operationally, as a facility requiring maintenance. This broad realization guided the selection of the integrated team. The students worked with owner-builders of a local climbing gym, world renown mountaineer Conrad Anker, an ice-farming expert, and a structural engineer.

As is the case with many real world projects, an unexpected twist changed the trajectory of the project. In the first design development progress presentation by the students to the

Figure 3: Bozeman Ice Tower - detail development of the climbing wall skin.

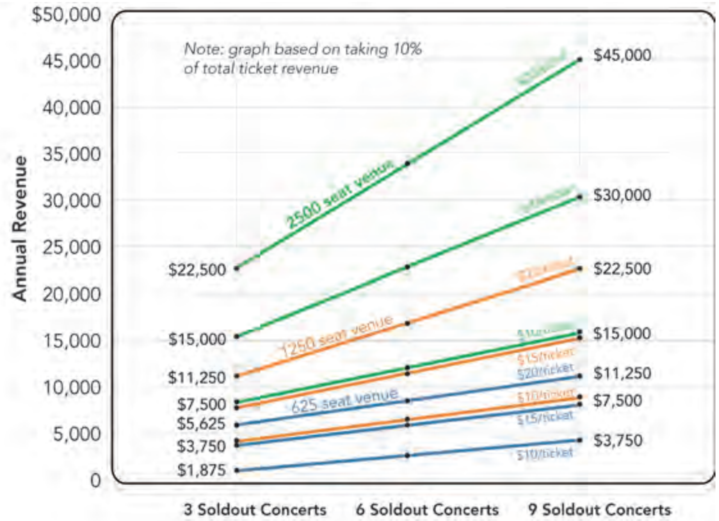

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Figure 4: project proforma and cost-benefit analysis.

county commissioners and the public, the program of the project, a climbing venue with an integrated outdoor event center, came under intense opposition. A small, but vocal, group of neighbors objected to the increase in events that the new outdoor performance venue would attract, citing increased noise disturbance.

The original winning design entry had proposed a multi-program approach to create an economically sustainable facility, one that would not require taxpayer support. Since the community opposition came at the beginning of the semester, students were able to recalibrate and collaborate with a team of Business School students in an entrepreneurship course offered at Montana State. The architecture students and business students worked together to complete a project proforma and cost-benefit analysis (Figure 4). The research supported the need for a hybrid programmatic approach to the project and concluded that the outdoor event venue had the least risk and highest potential for economic success. In addition to economics, the architecture students enlisted the help of acoustical engineering students to complete a sound survey of the surrounding area. The economic data and acoustic survey helped re-orient the community dialogue.

At the same time that programming became the main issue, students continued with development of the climbing skin. Team members used two strategies for the skin development: multiple iterations of computer modeled visualizations and real-life mocked-up prototypes of climbing surfaces installed at the local climbing gym, tested by gym members (Figure 3). The success of these approaches depended on the students' ability to clearly communicate ideas, comprehensively represent context and creatively illustrate opportunity to people, traditionally outside of the design development phase, with different competencies.

Diagrammatic visualizations of various design modifications which abated noise were correlated with actual performance data to further community discussion on the project programming. Students worked with community members and established a design, review, and consideration process that integrated community members as team collaborators, creating a new "think tank" to develop a win-win approach. The project is currently in the final fundraising phase and scheduled to be constructed within the next two years.

KHUMBU CLIMBING CENTER (KCC): CONSTRUCTION DOCUMENT AND ADMINISTRATION PHASE

Identifying and resolving problematic issues are a valuable part of the construction phase. Through skillful coordination with the builder, the building design becomes a physically constructed and occupied reality. The Khumbu Climbing Center (KCC) project is a climbing and community center in Phortse, Nepal, it is currently in the document and construction administration phase. The specific phase of construction for the KCC project was the fabrication of the primary floor trusses and framing and roof trusses.

A graduate of the architectural program was in Nepal during the course semester working on the construction and acting as the owner's on-site representative in coordinating the various trades. Students conducted weekly conference calls via Skype to monitor progress, follow up on construction changes and receive additional requests for information. The cloud-based project management software, "Basecamp", was used for documentation organization, storage, and issuance.

An important design concern in architectural practice that is not critically addressed in most architecture school is calibrating the complexity of the construction and detailing of the building project with the skills of those of the builder. This requires a deep understanding of the contractor and tradesman capabilities, knowledge of the design intent and dynamic appreciation of insight from expert tradesman doing the work. The construction administration phase is a unique opportunity to integrate real-time feedback loop design improvements. This particular project exaggerated the need to clearly understand the issues associated with construction such as tolerances, material compatibility, changes in material availability, and means and methods of construction. In more progressive architectural projects, standard construction methods of detailing are challenged, increasing the need for collaboration during the construction phase. In addition, this ambiguity increases the responsibility of the architect to navigate and be involved in construction coordination.

The floor construction for the KCC was designed to be light-gauge metal framing, a departure from the traditional wood framing done in Phortse. Floor and roof trusses were designed as hybrid wood and metal constructions, again, a departure from pure wood trusses. The non-standard designs represented a progressive move in material usage, responding to the fact that the last leg of material transportation involved "Yak and Back" portering to Phortse (Figure 5). The new constructions reduced cargo weight (and associated resources) by more than 60%. In order to implement these new constructions, students created "Ikea" type documents that graphically conveyed the information, requiring little or no words to understand the intent. The floor framing for the climbing center was completed in Phortse during the course of the semester.

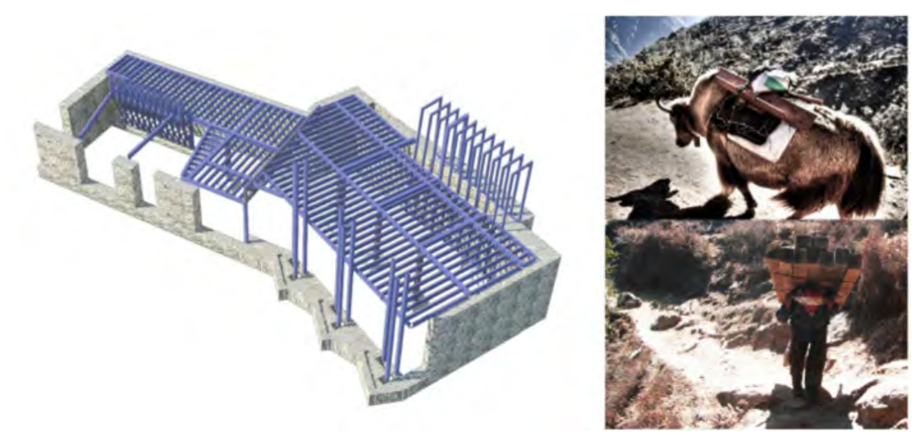

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Figure 5: Framing Plan for Khumbu Climbing School (left) had to consider Yak and Back transportation (right)

CONCLUSION

The day-to-day practice of architecture must navigate within a system of contexts often replete with competing values. This requires the process of design and construction to rely on constant tactile adjustment made by the demands of clients and consultants, with constraints of codes and budgets to address a landscape of contingency. Engaging these conflicts defines the profession of architecture. Without a strong architectural presence the authority of the designer diminishes.

Professional Practice curriculum lies at the intersection between the profession of Architecture and its academic partner. The pedagogical significance for students is learning the many and often conflicting values of the actors. If Professional Practice curriculum is to be a harbinger of architectural practice then it must seek out opportunities to engage architectural conflict and create paths of mutual benefits for the constituents involved.

The innovative pedagogical approach at Montana State provided students a unique educational opportunity to engage an iterative community design / architectural practice model, where real-time information and context feedback were embedded into core learning objectives. Each project had a unique issue, which provided an opportunity for the professional practice course to engage as part of the larger curriculum. The Sourdough Fire Station Project had to overcome two failed bond-issue votes directing the goals of classroom to explore financial considerations to public funding and how to effectively disseminate the values of a new station to the residents. The Bozeman Ice Tower began with resolving the technical conflict of the climbing wall envelope before public opposition lead to a radical shifting of social responsibility. A business model of the project was re-envisioned, augmenting the project program and expanding the vision to become a year-around multi-activity community venue. The conflict for the Khumbu Climbing Center was in the ability of the students to merge disparate values to complete the construction documentation and administration. The ethical values of the architect of introducing new materials and building techniques to meet the earthquake design requirements had to balanced with the traditional cultural values of the community by revising the design to adopt local recourses and use of yak-and back modes of transportation to the site.

Integrating a community design model into the professional practice course enriched the learning experience. It engaged practice on a parallel level, as opposed to a hierarchal level that happens in internship.

So where does it go from here? The Professional Practice model was developed to be repeatable. Searching for specific opportunities to engage the inherent conflicts that exist in the complexity of design projects. Community design projects open students to a field of values and shifting priorities requiring tactics of agility and the inventiveness of the designer.

Preventing Malaria through Housing Design

Malaria is an issue of global importance. This parasitic disease, which is transmitted through the bite of an infected mosquito, currently threatens 44% of the world's population. In 2013, there were an estimated 198 million infections and over 580,000 deaths from malaria. Like many diseases, malaria is opportunistic, quickly feeding into the cycle of poverty and infecting the most vulnerable members of society who lack access to protection and care. Sadly, it is the young children within these vulnerable populations who shoulder the greatest burden. Among all malaria-related deaths in Africa, which accounts for nine out of ten of all malaria deaths globally, 83% were among children under the age of 5 years.[1] The timely control of malaria is a priority, but the tools to achieve this are limited. Growing drug and insecticide resistance threatens our ability to effectively control malaria using currently available methods. As such, the diversification of available strategies is essential for building the required capacity to respond to the complex challenges associated with malaria control in the 21st century. To achieve this, it is imperative that practitioners from a variety of fields become actively engaged in designing, testing, and implementing high-impact strategies, such as mosquito-proof housing, which can effectively respond to the root causes of the world's most pressing health threats.

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CHALLENGES IN MALARIA CONTROL

Despite over half a million deaths each year, it is important to acknowledge that great strides have been made in the control of this devastating disease. Global mortality has fallen by 47% since 2000,[2] a success that has been largely due to the rollout of a new drug treatment, known as artemisinin-based combination therapy (ACT), and the global push to expand coverage of insecticide-treated bed nets (ITNs) and indoor residual spraying (IRS). With more lives being saved than ever before, it is easy to view these chemically based strategies as the penultimate step toward the eventual elimination of malaria. However, the persistent over-reliance on a limited array of functionally similar strategies jeopardizes future efforts to control and treat this disease.

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Drug and insecticide resistance is a significant threat. Resistance to artemisinin, the only remaining highly effective drug treatment for malaria, has already been reported in five countries in Southeast Asia.[3] Additionally, resistance to common insecticide compounds used globally in ITNs and IRS has already been reported in 78% of 63 surveyed countries. The rapid spread of resistance threatens to reverse past health gains and renders our most powerful tools against malaria obsolete, thereby cutting off our ability to protect and treat the 3.2 billion people currently at risk around the world.[4]

It is also important to note that control strategies like ITN and IRS may not always offer protection as intended. While ITNs are highly successful public health interventions—low-cost, easy to distribute, and efficacious—full protection requires unwavering use by all members of the household. In reality there is often a gap between ITN ownership and actual use, which leaves people exposed to potential mosquito bites and, therefore, infection. The reasons for this disconnect are complex. According to recent research, the most frequently cited reason for lack of regular ITN use was due to discomfort from poor airflow and high temperatures while sleeping under the netting. Furthermore, the failure of the ITN to conform to the family's sleeping patterns and the perception of malaria infection as a low risk were common reasons for net disuse.[5,6] These findings certainly do not imply that ITNs should be discontinued, but rather highlight clear opportunities to better understand how people choose to interact with their built environment and prioritize health risks. By understanding these variables within the broader context of disease transmission, we can create solutions targeted to extend protection across current gaps.

HOUSING DESIGN AS A STRATEGY FOR MALARIA CONTROL

The use of housing modifications as a strategy to prevent malaria is not a novel concept. The expansion of higher quality housing in Europe and the United States played a significant role in the reduction of malaria in early 20th century on both continents.[7] The structure of the home plays a key role in the ecology of malaria transmission, as most Anopheles, the species of mosquito responsible for transmitting malaria, prefer to bite after dusk, when most people are sleeping inside their homes. Due to this specific biting preference, an estimated 80% of malaria transmission in Africa occurs inside the home.[8]

Inadequately constructed housing allows mosquitoes easy entry into the indoor living environment (Figure 1). Characteristics like open eaves, unscreened windows and doors, mud or thatch walls and roofs, and lack of ceilings are all risk factors for mosquito entry.[9,10] Simple modifications to home design, such as sealing eaves, directly respond to these unique behavioral characteristics of the mosquito and significantly reduce mosquito entry into the home, thereby decreasing risk of infection for all residents.

Various housing characteristics and design modifications have been tested in the field in order to quantitatively describe the potential for protection against malaria. This protectiveness has been measured in several ways depending on the scope and design of the research. In some cases, mosquito entry into the living environment (i.e. the number of Anopheles mosquitoes inside the home) was used as a measure of risk. For example, a study completed in a highly malarious region of Kenya tested the impact of installing low-cost, locally produced ceilings against mosquito entry into the home. Findings showed a 76-82% reduction in entry among homes with the modified ceilings, thus demonstrating the potential for the application of simple design modifications to protect residents in high-risk areas[11] regardless of ITN use. A similar trial, which was completed in the Gambia, also found that the installation of plastic screened ceilings reduced the entry of mosquitoes by 80.1%, when compared to controls.[12]

Figure 1: Example of Cameroonian home with high risk of mosquito entry (ARCHIVE Global, 2013)

Other research has sought to link the quality of home design to actual rates of malaria infection among residents. Research completed in Burkina Faso found that young children living in homes with mud roofs had greater than two times the odds of having a malaria infection than children living in homes with iron roofs.[13] Similar results have been documented in studies from South Asia. Research carried out in Sri Lanka identified significantly higher malaria incidence among residents living in poorly constructed homes, 21.2%, when compared to residents living in adequately constructed homes, 10.5%.[14]

In addition to this research, there has been some limited, yet important, research that assesses residents' receptiveness towards a given mosquito-proofing modification. Upon completion of a trial in the Gambia that tested the efficacy of full home screening, 94% of participants chose to keep the screening in their homes. Residents cited that the screening not only prevented the entry of mosquitoes, but also improved their privacy and beautified their home.[15]

OPPORTUNITIES FOR IMPACT

While the initial investment into housing modifications as a malaria prevention strategy may be considerably greater than that of current control strategies like ITNs or IRS, the benefits are significant and potentially more valuable to the user. The function of housing modifications is not dependent on drug resistance and does not require repeated investment over decades or long-term behavior change. Additionally, coverage at the home level is equitable, extending a level of protection to all residents sleeping inside the home regardless of net use (Figure 2). Perhaps most critically, housing modifications may have the power to appeal to the user through the addition of actual and/or perceived value to the home, both financial and sentimental, while simultaneously protecting against a serious health threat that is not necessarily deemed a priority.

By shifting from research to practice, the expansion of high-quality housing can assist in addressing the health challenges that rapidly growing countries in Africa will face in the coming decades. Unprecedented population growth in urban centers will lead to the proliferation of living conditions that will result in a growing burden of diseases associated with poverty. Such a scenario will require cities to care for a greater number of needy residents than every before. Further compounding this issue, the inescapable increase in drug and insecticide resistance will mean that these diseases, like malaria, will be more difficult to treat and control chemically. In the face of these coming challenges, a broader understanding of how housing can be used in conjunction with currently used prevention strategies will be necessary.


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Figure 2: Comparison of protection types. (ARCHIVE Global, 2015)

SHIFTING FROM RESEARCH TO PRACTICE: MOSQUITO-PROOF HOUSING IN CAMEROON

In response to the clear need for the application of alternative strategies to prevent malaria transmission in vulnerable communities, ARCHIVE Global is working to put these findings into practice in the field. ARCHIVE Global is an international non-profit organization that seeks to reduce the dual burden of poverty and disease through the delivery of housing design support in low-income communities around the world. In addition to the organization's global portfolio of projects, ARCHIVE Global is currently working with the Cameroon

Coalition Against Malaria (CCAM) to design, test, and deliver mosquito-proof housing in the peri-urban community of Minkoameyos, Cameroon.[16]

Malaria remains one of the three main causes of sickness and death in Cameroon. According to findings from the World Health Organization (WHO) in 2010, just 14% of Cameroonian children under five slept under an ITN every night.[17] This is paralleled by the high prevalence of poorly constructed housing, particularly in rapidly growing peri-urban settlements. Given this high burden of malaria and poor housing, as well as low ITN use, the application of simple housing modifications as a supplemental prevention measure has the potential to dramatically reduce local transmission, as well as provide practical evidence to inform policy at a national and international level.

ARCHIVE Global and CCAM launched the Building Malaria Prevention (BMP) project in 2013 with the goal of 1) extending mosquito-proof housing to over 260 homes in Minkoameyos, chosen based on a comprehensive selection criteria developed to identify the most at risk homes; and 2) collecting clear evidence of health impact that can be used to demonstrate the value of housing as malaria prevention. The project is comprised of 3 major components: design and construction, community training and advocacy, and malaria research.

As previously mentioned, one of the most common reasons for poor ITN use is discomfort while sleeping. To prevent the similar stagnation of air following the sealing of eaves and other openings, care is taken during the design process to install strategically placed screened windows to passively boost air change within the home and, as a result, maintain a cooler indoor temperature. Other modifications include the sealing of open eaves, installation of screened windows and doors, plastering of cracked walls, and targeted improvement of drainage around the foundation of the home to eliminate potential mosquito breeding sites. Figure 3 depicts a rendering of a completed beneficiary family's home from 2014. Upon completion of the project in December 2015, an estimated 1,500 residents will be living in healthy, mosquito-proof housing and over 4,000 members of the Minkoameyos community will have participated in training workshops that focus on using home design to protect against malaria. [18]

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Figure 3: Example of a mosquito-proof housing design (ARCHIVE Global, 2013)

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By rolling out the BMP project in Minkoameyos, ARCHIVE Global and our partners seek to demonstrate the feasibility of implementing this approach at a national and international level though the use of local material, labor, and expertise. The work in Minkoameyos will hopefully lead to broader support for and roll out of similar projects throughout the malaria-affected world. It is clear that repetition and experimentation will be important to refine implementation strategies and to most effectively address the region-specific combinations of housing type, culture, environment, and disease.

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Figure 4: Beneficiary home pre-renovation

Figure 5: Beneficiary home post-renovation

CONCLUSION

As shifts in population growth, living patterns, and climate continue to impact the complex global system in yet unknowable ways, it is increasingly important to apply our limited resources toward designing strategies and policies that respond to root causes of poverty and disease, rather than the symptoms. In the case of global health, attention is often focused on reactionary control measures that so often fail to address the root causes of transmission. Avoiding this outcome will require practitioners to reach across disciplines for solutions that speak to the complexity of the issues being addressed. The fields of architecture, design, and planning will have a fundamental role to play in this process.

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