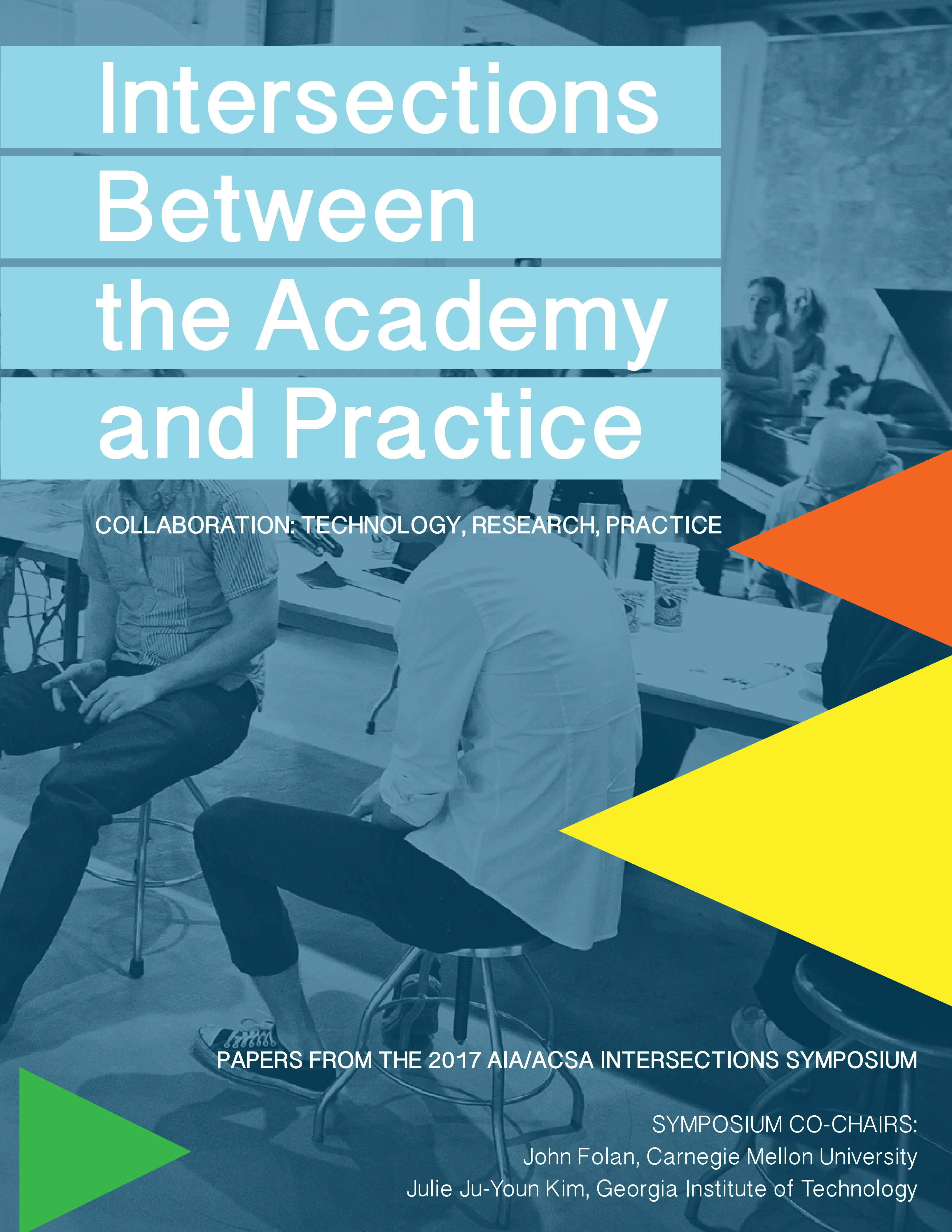

Intersections Between the Academy and Practice

COLLABORATION: TECHNOLOGY, RESEARCH, PRACTICE

PAPERS FROM THE 2017 AIA/ACSA INTERSECTIONS SYMPOSIUM

SYMPOSIUM CO-CHAIRS:
John Folan, Carnegie Mellon University
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ABOUT THE SYMPOSIUM

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The American Institute of Architects (AIA) and the Association of Collegiate Schools of Architecture (ACSA) are pleased to partner on this 3rd annual symposium, dedicated to the integration of education, research and practice of technologies at the 2017 AIA National Conference in Orlando. This symposium focuses on COLLABORATION. New technology and ways of working are helping to break down barriers between the different players in the construction process. Industry leaders already do a great deal to encourage collaboration among their teams, providing vision, collaboration-conducive work environments, collaboration technology, and by removing obstacles. Collaboration also happens outside the traditional AEC industry, between architects and cognitive scientists, between architects and community organizers, etc.

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CONTENTS

INTERSECTIONS Between the Academy and Practice Collaboration: Technology, Reserach, Practice

SYMPOSIUM CO-CHAIRS
John Folan, Carnegie Mellon University
Julie Ju-Youn Kim, Georgia Institute of Technology

INTRODUCTION

The content included in this volume provides several demonstrable models for how the architectural academy and practice might intersect with greater efficacy and frequency. The writing is unilaterally optimistic –not because it is speculative, but rather because it chronicles processes and methods that have been tested in application. While presented through a set of distinct lenses, all of the work reinforces the underlying positive sensibility inherent in collaboration – collective intelligence. Diverse in scale, scope, and focus, each offers critical assessment of applied knowledge gained through experience. Simultaneously, while diverse, each communicates strategies that are transferrable across those same platform boundaries. In several cases, the work and methodologies chronicled are retroactive in nature, examining the DNA of a building process; oriented toward scientific analysis of how collaborative process might have yielded better performance. In others, the work illustrates alternative models of practice and project team building that can enhance ecological resilience. All of the topics addressed by the authors are timely, relevant to contemporary architectural education and practice, and have been curated to illuminate potential.

Writing about material investigations and industry research collaborations most directly identifies areas for concern that will need to be addressed as the academy and practice seek more opportunities to intersect. Several questions emerge. What are the implications to academic freedom when funding is tied to performance based deliverables? What are the implications to pedagogy necessary for fundamental skill development? With universities and schools of architecture under increasing pressure to offset capital and operational costs, what are the best models of professional/academic collaboration that will ensure ethical constancy within both realms? Issues identified in these proceedings set the table for necessary discourse and seek to perpetuate the relevance of future Intersections Symposia.

As co-chairs of this Intersections symposium, we would be remiss if we did not recognize the efforts of our predecessors. The success in attracting the quality of papers included here across the domains of technology, research and practice is evidence of an inherited legacy and forum for discourse. Without the support of the American Institute of Architects and Association of Collegiate Schools of Architecture, and their foresight in providing a platform for this exchange, the work of everyone represented in these proceedings would not be possible. We would like to express our personal gratitude to co-conspirators in the production of this volume, Eric Wayne Ellis, ACSA Director of Operations and Programs, Ming Hu, former AIA Director of Academic Engagement, and Nissa Dahlin-Brown, present AIA Director of Academic Engagement. Without their efforts, the diversity and scope of what is discussed would not have been as broad or focused in setting the stage for future Intersections Symposia. As with the content represented in this volume, the work in preparation was and is the result of our collaboration with many others.

-John Folan and Julie Ju-Youn Kim, Co-Chairs

The Building Genome Project: Indentify faults in building energy performance

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This paper explores the use of new tools for the creation of novel methods of identifying faults in building energy performance remotely. With the rise in availability of interval utility data and the proliferation of machine learning processes, new methods are arising which promise to bridge the gap between architects, engineers, auditors, operators, and utility personnel. Utility use information, viewed with sufficient granularity, can offer a sort of "genome," that is a set of "genes" which are unique to a given building and can be decoded to provide information about the building's performance. The applications of algorithms to a large data set of these "genomes" can identify patterns across many buildings, providing the opportunity for identifying mechanical faults in a much larger sample of buildings that could previously be evaluated using traditional methods.

INTRODUCTION

In terms of buildings sciences, the energy performance of a building represents an outcome that has been generated through a myriad of disciplinary interactions. For example, performance is dependent on the shape of the building and the materials chosen by the architect, the mechanical systems are designed by the mechanical engineer, the maintenance of systems by the building operators, and the way the building is used – control settings etc., is determined by individual end users. With so many and varying pieces, expertise, and interests controlling a single outcome, it is perhaps no wonder that much of our existing building stock suffers from faults in energy performance design, operation, or construction.

The traditional method for uncovering building energy performance faults has been through the energy audit, a process by which a skilled analyst thoroughly surveys the building and relevant information about the building, both on and offsite. The general purpose of the audit is to identify problem areas and ascertain changes that can be made to enhance energy performance. While this tried and true method has doubtlessly produced measurable gains in the performance of individual buildings, it is not without its limitations. Audits are time consuming and labor intensive, requiring specially trained professions capable of evaluating the interdisciplinary complexity of building energy systems – one building at a time. As a result only a very small portion of the total building stock can receive this valuable service in any given year. Audits are also something of a "snapshot" of a building, in that the auditor generally visits only for a short time and is able to observe only very limited operations first hand and follow up visits are even more time consuming and expensive. This means that many audited building have faults that go unidentified and continue to damage ongoing building energy performance even after close examination.

In order to improve the range and persistence of building energy performance analysis, new tools are needed that can evaluate much larger portions of the stock much more efficiently. Ideally, such tools would be capable of producing the type of analysis previously generated by energy audits in much more expedient and cost effective way. It would also be capable of seeing building performance for a far longer period of time, identifying patterns and thereby exposing faults which may be visible only over many months for example.

BUILDING ENERGY IN THE AGE OF BIG DATA

The simplest utility meters are those which measure use continuously and generate some value for usage which can be read and recorded manually one time for each utility billing cycle. For the problem of documenting usage in a given month to allow for accurate billing, these simple meters may prove adequate. However, advances in metering technology over the past decades have significantly expanded the scope and amount of data which can be collected and analyzed.

For example, electrical meters which measure consumption on much shorter "intervals" (15 seconds in some cases) are now becoming commonplace. These interval measurements allow for the monitoring of energy consumption on a functionally real-time basis, improving both the feedback and the ability to find common faults in usage patterns that previously were available only to expensive, smart building automation systems (BAS).

An example of collected electrical Interval utility data can be seen in Figure 1. This data belongs to a school in Illinois, and has been recorded every half-hour. The red line on the graph represents electrical use for a single day, in this case September 15, 2010. On this day, it

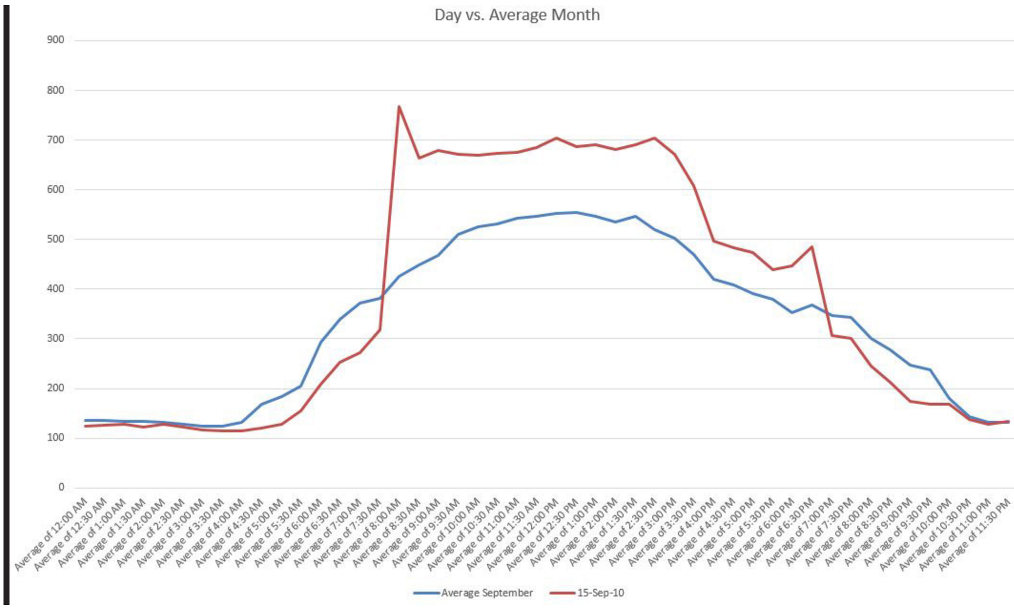


Figure 01: Eletrical Utility Load Profile for a School Building for the month of Semptember (Blue) and the day of September 15 (Red)

is visible that the early morning hours exhibit relatively low and consistent electricity usage. This likely represents a 'base load'. The term base load denotes the electricity which is constantly and consistently used by a building for always-on functions The blue line, represents the average electricity use throughout the day for the entire month of September. It paints a slightly different, although not incongruous picture. The blue, monthly line is slightly lower, which could be caused by changes in weather over the course of the month, or could simply reflect that weekends, when energy use is low, are included in this daily use curve. The curve is a bit smoother, with less of a plateau, which is not uncommon, as monthly curves tend to "average out" outlier values. For example, it may have been rainy in the morning with the skies clearing later in the day. This is captured by fine grained interval data, but gets averaged out in monthly data.

In this case, the "utility curves" reflect approximately what we might expect from a school. That is, the school uses little energy at night, has a period of very high usage while school is in session, and then a period of lower usage as evening activities take place, gradually reducing until all activities are over. One may note that usage appears higher than one would expect in the late evening, but there are a number of possible explanations for this, from late-night custodial work to errantly scheduled mechanical systems.

In the case of a single building, this type of analysis is straightforward and easy to see and quickly digest. The single day utility curve was generated with only 48 values. The monthly utility curve was generated with a more robust but still manageable 1,440 values. As one "zooms out," however, the picture becomes much more complicated. If this meter was installed in September 2010, then at the date of this writing, it has been operational for 76 months, or something like 2,300 days, meaning it has collected well over 100,000 readings. Multiply this number by the thousands of buildings with smart meters installed, and the data stream quickly overwhelms our ability to provide this type of analysis for the entire building stock.

In this paper, we propose applying machine learning and genomic testing techniques to the problem of identifying energy performance faults in large numbers of buildings quickly and continuously – without human intervention. In the following sections we first review the literature on remote building energy modeling, we then propose expanding on that work with the introduction of a new remote energy analysis approach. We follow with information regarding the potential of the tool and some of the obstacles to its creation. We then provide our conceptualization of the way forward including genomic analysis. We conclude with thoughts on future research and next steps.

PREVIOUD WORK ON INTERVAL UTILITY DATA

[In recent years, there has been some academic interest in interval utility data and what it can reveal about buildings from a distance. Aksoezen et al (2014) focuses on the relationship between interval utility data and buildings with known parameters in an effort to find a correlation between building attributes and energy performance. Other research, such as that by Edwards et al (2012), has had a focus which is more predictive in nature, in this case using interval utility data to try and predict "next hour" consumption. Similarly, Espinoza et al (2005) considered utility data at the substation level with an eye toward predictive analytics. They were able to cluster substations into groups (e.g. residential, business) using utility profile analytics to work through end use analysis.

Still other work has focused on using interval data to discern building occupants building use patterns, rather than focusing on just the buildings themselves. Albert and Rajagopal (2006) use smart meter data to try and predict both occupancy and the characteristics of building users. Similarly, Kwac et al (2013) find some success using interval utility data from specific homes to segment utility customers by their lifestyles. The roll of occupant behavior as it relates to energy is also explored by Santin et al (2009), who try to evaluate how great of an impact occupant behavior can have on heating and cooling energy use, again relying on residential hourly load profiles.

This type of data has even been used specifically to identify energy faults in buildings to some degree. For example, Brown et al (2009) monitor water, electricity, and gas use for 300 buildings over a seven year period. Using water as a proxy for occupancy and comparing this to the utility profiles, they were able to identify four common heating failure modes.

In terms of the private, building energy analysis sector, we find at least three companies who currently claim the ability to perform limited, auditing-type tasks with no building visits or minimal building visits, to wit FirstFuel, Agilis Energy, and Retroficiency (Lee et al 2014). Unfortunately, these are private entities with proprietary algorithms, so their methods and efficaciousness is difficult to ascertain.

Other research use a classification and regression tree (CART) algorithm to disaggregate energy usage using expert rules and then use statistical methods to identify outliers to identify faults. Lie et al (2010) examine this method for detecting abnormal electrical consumption for lighting in buildings. Using past electrical consumption records, occupancy, and time of day (as a surrogate for daylighting contribution), a decision tree is constructed using occupancy and time of day as independent variables. The analysis identified outliers when occupancy was low, yet electrical consumption was high. Khan et. al (2013) examined three different data mining techniques for detecting abnormal lighting energy consumption using hourly recorded energy consumption and peak demand (maximum power) data. CART, K-Means, and density-based spatial clustering of applications with noise (DBSCAN) were used. Interval meters can represent massive amounts of data which depend on some type of large-scale data analytics techniques.

Machine learning techniques that learn from data are now being developed. In one example, Lee et. al (2004) examine using a general regression neural-network (GRNN) model for on-line detection at the subsystem level. Energy fault detection techniques have also been embedded in building automation systems. They typically rely on a system of rules to determine a conditional probability for each of a plurality of possible fault causes given the detected fault (United States Patent Application, 2011, 2014). In this case the inputs to the system are embedded in the BAS.

While the academic literature would seem to fill in bits and pieces of what can be accomplished by applying data analytics to interval utility data, it seems as though no complete process has emerged that allows for remote auditing and fault detection. While the tools looked at in the private sector seem to have promise in the targeted evaluation of a client's building or portfolio of buildings, their inner-workings and exact capabilities remains opaque. Today, there exists no publically available means of evaluating interval utility data across wide numbers of buildings to detect energy performance faults in an efficient and low-cost way.

DEVELOPING THE TOOLS

Clearly, there exists a need for a tool which can put this data to its optimal use. With advances in machine learning, it would seem plausible that a program could be developed with would be capable of review huge amounts of utility data and finding anomalies. Unfortunately, the real problem of creating such a tool is not so straightforward.

First, there exists the problem of having a basis for comparison. If one imagines being given a utility profile and asked to find faults by comparing to some baseline, the question would quickly emerge as to what should represent the baseline. There seems to be, at minimum, three methods by which "standard behavior" could be established

Comparison to Self

Perhaps the simplest method of identifying faults would be comparing the current performance of a building to its past performance or performance under another condition. This method has the advantage of not requiring a large library of utility data for comparison, but would rather enable one to find anomalous data within the frame of just one building, if the building had been generating data for some period of time.

An example of this kind of analysis can be seen in Figure 02. Figure two represents the average, weekday, non-holiday energy consumption of a school for three months, June (blue), July (orange), and August (gray). Even without an outside basis for comparison, an anomaly appears immediately visible. Though the data appears phase-shifted, it is simple to see that in June and August, electricity seems to have a longer midday plateau. In contrast, July seems to have a sharp dip right at the center of the day. Considering that the summer schedule for this school was consistent throughout these three months, clearly something was changed operationally in this July, and then apparently changed back in August.

It could be that cooling equipment was set back in July, while it was allowed to cool an unoccupied building in part or all of June and August. It could be that lighting was turned on or off at different hours in this time. It could be that a piece of equipment was not operating and, therefore, not consuming power. Whatever the explanation, the anomaly is clear through comparing how the building operated at one point to how it operated at another.

This strategy has the downside of requiring some information about the building. Without knowing that the operation schedule had been static in this month, the anomaly detected could have been dismissed as a simple temporary change in use. Without know that the building was a school, its seasonality of operation would make little sense.

Comparison to a 'Real' Reference Building

If there is not a long history of interval utility operation, or information about context is unavailable, a more complicated method may be called for. Instead of comparing a buildings current operation to older operation, or comparing June to July, it may be more sensible to compare the operation of a school to the operation of all other schools in the same area or under the same climate conditions.

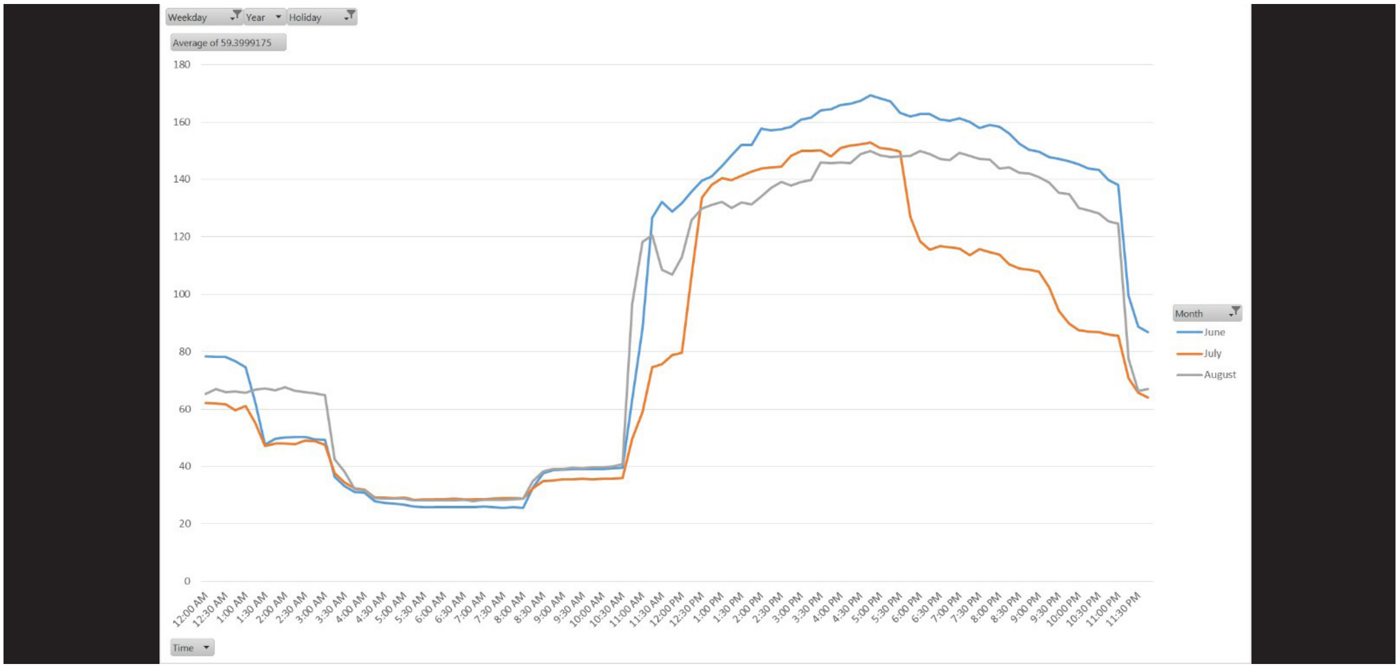


Figure 02: Electrical Utility Profiles for a school building in June (Blue), July (Orange) and August (Gray).

Of course, not all schools have similar utility curves. These can be affected by many variables including size, schedule, occupancy, and mechanical configuration. Yet, with a sufficient number of schools, one could ostensibly generate a "standard school profile" based on a library of data. Faults could then be detected in any one building by comparing it to the "standard" profile and recognizing where sharp differences occurred.

In a sense, this is not that different form the common practice of "benchmarking." Benchmarking compares the energy consumption of a building, usually on a normalized per unit area basis, to the consumption of a library of similar buildings. This technique has long been used to compare a subject building to the building stock as a whole. An interval utility comparison would be similar, except instead of making one comparison for one year, it would be capable of making thousands of comparisons at every half hour.

The downside to this method is that it requires a great deal of similar buildings to create a baseline for comparison. Because comparison of just a few buildings would be susceptible to "noise" in the data, a large sample of utility data would be required. It would also require knowing which utility streams belonged to buildings, or having an algorithm capable of making this distinction.

Comparison to a 'Simulated' Reference Building

Where a database of similar buildings is unavailable, or where the buildings are too distinct from one another to create a true average profile for comparison, the most sensible method may be comparing the real-world utility profile of a given building to a simulated utility profile.

Consider the example building shown in Figure 03. In these two graphs, the real utility profile of an academic building on the University of Illinois Campus (called the "Bill" profile, i.e. from utility bills) is compared to an output of a simulated version of the building (called the "Model" profile, i.e. from an energy model). Because the model is impervious to things like equipment breaking or errors of operation, it can represent how the building "should" perform. In looking at this example, we see the building is using more steam that would be expected during the spring shoulder season. Likewise, the building is using less electricity than expected in June, and more in September.

METHODOLOGICAL CONSTRUCTION

Our methodology for defining acceptable energy use patterns for a particular building includes using real and simulated reference data to detect degradations in energy efficiency performance of a particular building, and to diagnose probable faults. A preliminary flow chart for this process is shown in Figure 04. It shows the relationship between data management, analytical process, and reporting necessary to accomplish this goal. The high-level logic for our automated process includes using energy consumption data along with building classification information to first identify the correct building reference and then to diagnose potential energy-wasting faults in individual buildings in a continuous analytical process.

Building Screening

Continuous fault detection and diagnostic analysis provides information at a rate much faster than an organization's ability to respond with appropriate follow-up analysis and physical repairs. We propose a selection process that prioritizes buildings with the greatest savings potential. The process parameters can be adjusted to select for the desired number of buildings. Several metrics could be used as an initial screening process when selecting buildings for fault detection and diagnostic analysis. Calculation and comparison of total energy use,

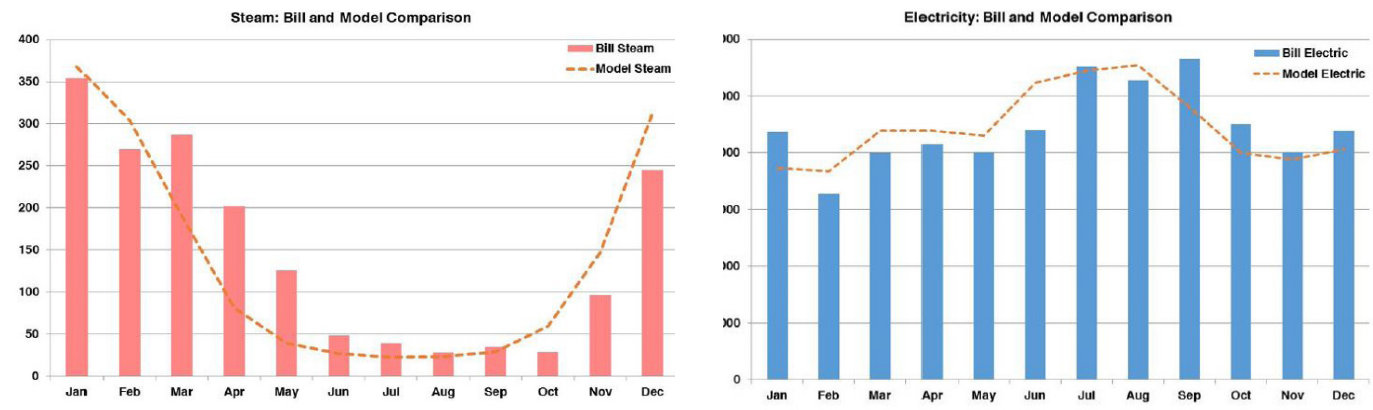
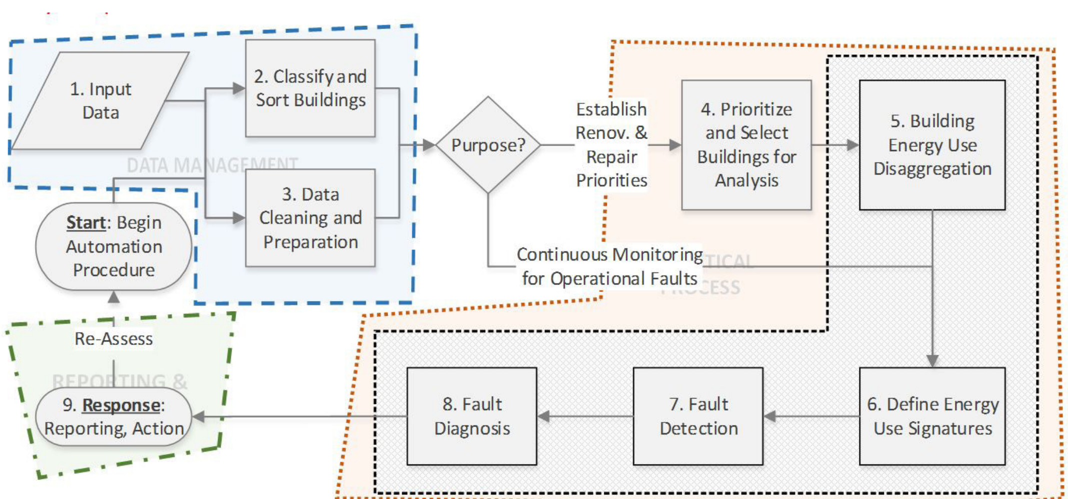


Figure 03: Comparision of Bill and Model Profiles on an annualized basis.



[Figure 04: A flow chart describing the automated process that uses energy consumption data and limted building information to identify and diagnose energy-wasting faults

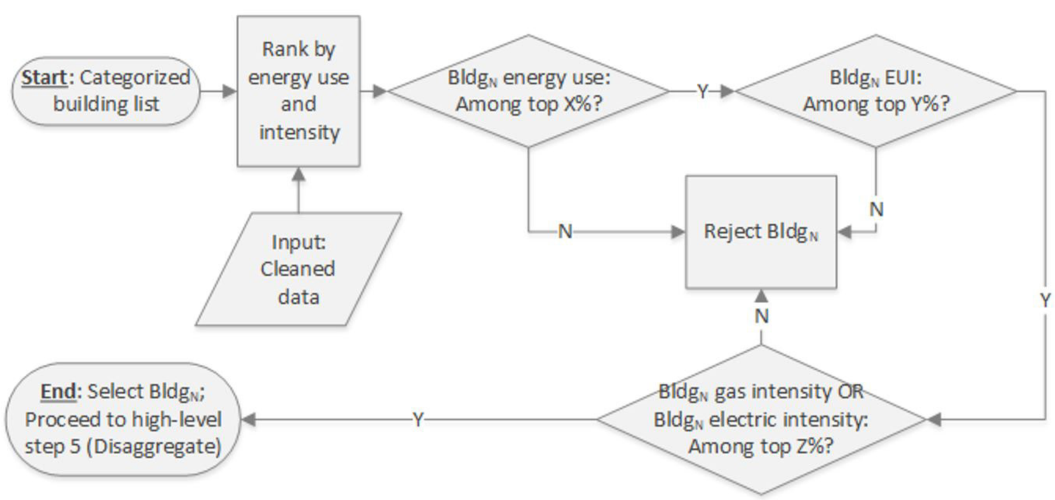


Figure 05: Example of a possible screening process that prioritizes and selects buildings for fault detection and diagnostic analysis.

energy use intensity (kBtu/ft2-year), electricity use intensity (kWh/ft2-year), and natural gas use intensity (therms/ft2-year) are among the parameters used in the screening process. Figure XX provides an example of a possible screening process.

Genomic Optimization Techniques.

One technique which has been explored is genomic modeling. Genomic modeling is an iterative, minimum-seeking algorithm. While it was originally designed for optimization and not classification problems, the challenge of matching utility profiles to a set of building "traits" which most likely generated them makes for a novel application.

In this process, a solution space of buildings with random "traits" are generated, then the "fittest" solutions move on to the next "generation." Fitness is determined, in this case, by the cost of function of aggregate difference from the given utility profile. Using this method, it is possible to find the set of building faults (in a fault detection example) or parameters (in a classification example), which are most likely to generate utility profiles like a given subject utility profile. While this approach is nascent, its early returns are promising.

CONCLUSION

The development and testing of such a technology would involve the cooperation of multiple independent actors. It requires Architects that can classify buildings; Building Energy Specialist who can correctly diagnose energy profiles; utility customers to share their data; computer scientists to automate the processes described - thousands of times per second.

Yet, if successfully developed, the technology has potential to allow all of these stakeholders to cooperate in new and interesting ways. Building engineers would be able to look up anomalous performance in their buildings and check them against a huge dataset to figure out what is likely causing the anomaly. Utility companies could send out annual reports to building owners showing potential faults in operations and potential ways to 'fix' them. Architects could specify systems by looking at the most common failure modalities in specific types of buildings in specific locations or working to address these potential faults in the design phase – to effectively 'nip it in the bud'. Policy officials could optimally allocate retrofitting incentives where their return on investment in terms of energy savings could be optimized. Monitoring companies could alert building engineers within seconds of a system fault or failure.

Decoding the building genome would require an immense amount of interdisciplinary cooperation and understanding, just as was the case in decoding the human genome. Yet, the collaboration required to create these tools would be sure to spur more collaboration, as the barriers that exist between project stakeholders, each with his/her own incentives and aims, could be substantially reduced.

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Buoyant Ecologies: Research, Collaboration, and Resilience at the Edge

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Buoyant Ecologies is a collaborative research platform that brings together architects, marine ecologists, and fabricators to address the implications of sea level rise through innovative approaches to designing and constructing resilient waterfront structures. This paper describes how the project's unique collaborative structure incorporates expertise from ecological researchers and industry manufacturers to promote recursive, interdisciplinary feedback loops between speculative thinking and pragmatic knowledge.

1. INTRODUCTION

Current climate change models offer a range of projections for sea level rise due to increases in global warming. In 2012, the U.S. National Oceanic and Atmospheric Administration published an assessment confirming that there is a 90% chance that global mean sea level rise by the year 2100 will fall within the range of 0.2 to 2.0 meters.[1] More recent studies project even greater increases, up to 15 meters by the year 2500.[2] Regardless of the precision of these models, even the lowest estimates present grave challenges for coastal cities. In the United States, nearly 40% of the population lives in coastal regions vulnerable to sea level rise; globally, the world's eight of the ten largest cities are coastal cities.[3]

This paper describes the research and pedagogical framework of Buoyant Ecologies, an ongoing collaborative research platform that brings together architects, marine ecologists, fabricators, and public regulatory agencies to address the realities and implications of sea level rise through innovative approaches to designing and constructing waterfront structures. The project begins with the premise that cities must accept the eventuality of sea level rise and actively develop new alternatives to the conventional ways that humans occupy urban waterfronts. Resisting two common urban responses to sea level rise—the construction of fixed seawalls and defensive barriers, and the impulse to retreat to higher ground—this project instead explores more resilient approaches to waterfront structures that can both adapt to rising sea levels and enhance the surrounding ecosystem.

The paper focuses on the first phase of the Buoyant Ecologies project: the development of material strategies for the construction of buoyant, sessile (or stationary) structures, using customized fiber-reinforced polymer (FRP) composite substrates, commonly known as fiberglass. The project seeks to develop high-performance envelopes constructed of custom-contoured FRP panels that, through their variation in topography, are optimized to provide a range of scalar habitats for marine life (both animals and plants), thereby contributing to the biodiversity of the ecosystem at large. As this kind of research necessitates knowledge and expertise far outside the realm of traditional architectural design, the project's collaborative nature—and the integration of collaborative workflows into the pedagogy of an architecture studio—becomes paramount. This paper describes the project's collaborative structure and how an integrated approach to architectural design, science, and manufacturing can facilitate a unique and productive feedback between speculation and empirical testing. It argues that such a pedagogy enables speculative thinking and pragmatic knowledge to inform each other in ways that would not be possible without an expanded field of expertise, and that this kind of feedback is essential for architects looking to expand design agency beyond the traditional limits of the discipline.

2. RESEARCH FRAMEWORK

Floating structures offer several advantages in regard to coastal resilience. Buoyancy decouples a structure from the ground, eliminating its vulnerability to flooding; in this regard, buoyant vessels are essentially invulnerable to sea level rise. Furthermore, buoyant structures can perform as wave attenuation devices, mitigating coastal erosion and helping to protect shorelines from flooding and storm surge events. However, environmental and regulatory groups—particularly in the San Francisco Bay, the site of this research—typically frown upon the construction of floating structures, as they are considered "fill" that encroaches on the Bay, reduces natural light, and threatens the health of underwater ecologies. This project seeks to invert that assumption by arguing that the underside of floating structures can perform as an upside-down benthic habitat for marine life, and that this surface can be optimized to provide multi-scalar habitats that maintain or increase biodiversity.

The project began in 2014 with an architectural design studio at California College of the Arts, run in collaboration with the Pier 9 Workshop, a state-of-the-art fabrication facility operated by the design technology giant Autodesk on the San Francisco Embarcadero.[4] Autodesk was interested in prototyping visions of a floating extension to the workshop as way to expand their facility's public presence and outreach to the city. The studio instructors sought to position this project as a critique of the defunct Google Barge, which had just recently suffered a very public banishment from San Francisco after failing to secure the approval of city and state regulators.[5] Rather than proposing the structure as a conventional building on top of a conventional barge, the team began to imagine a more integrated approach that would merge material and ecological performance into a new kind of architectural typology.

These initial conversations, although entirely hypothetical and speculative, were critical for catalyzing the partnerships and interdisciplinary feedbacks that continue to inform the research. Speculation about a floating structure's ability to foster ecological growth led to the Benthic Lab at Moss Landing Marine Laboratories, a research group focused on the benthos, or the bottom layer, of marine habitats. These ecologists, led by lab director John Oliver, are experts in the communities of invertebrate animals that accumulate on underwater surfaces, and they immediately recognized an opportunity in embracing such growth on the underside of a floating structure. Similarly, research into fiberglass, a material commonly used in boatbuilding, led to Kreysler & Associates, a composites manufacturer in American Canyon, California, who had just recently completed the fabrication of the FRP facade for Snohetta's new extension to San Francisco Museum of Modern Art. With years of FRP fabrication experience in both marine and architectural realms, founder Bill Kreysler reinforced the notion that a large-scale floating structure fabricated from FRP composites was buildable. Together these two partners helped transform a rudimentary hypothesis—what if a floating building could help the surrounding ecosystem rather than harm it?—into a viable research premise.

3. OPTIMIZED UPSIDE-DOWN BENTHOS ON CUSTOMIZED FIBER-REINFORCED POLYMER SUBSTRATES

The expertise of the Benthic Lab ecologists relates to understanding the tremendous impact of benthic communities of invertebrates on broader ecological health and resilience. These small animals are notable for colonizing any hard substrate—rocks, concrete sea walls, steel piers, docks, boat bottoms, and so on. Their unchecked growth, commonly referred to as "fouling communities," is often viewed as a nuisance; boats are regularly scraped clean to remove the barnacles and other organisms that compromise hydrodynamic performance. Nevertheless, as prey for larger fish and mammals, benthic invertebrates represent an essential part of the food chain, and the biodiversity of these communities directly affects the health of the broader ecosystem and its long term resilience in adapting to the effects of climate change.[6] As with many ecological systems, benthic communities are threatened by the presence of invasive species, which tend to be dominant and result in entirely homogeneous colonization; this is particularly acute in San Francisco Bay, which contains the most non-native species of any coastal estuary worldwide.

This research seeks to address the problem of biodiversity not by eliminating invasives—which is virtually impossible at this point—but by recognizing the latent opportunities of upside-down "fouled" surfaces like boat bottoms, docks, and other waterfront structures. The central premise of the research inverts the notion that fouling is a nuisance, instead embracing it as an untapped opportunity to facilitate diverse communities of invertebrates that contribute to the ecosystem's overall diversity. The hypothesis proposes that the geometry of underwater surfaces can be designed to produce "hillocks" and "valleys" of variable sizes, optimized to produce multi-scalar habitats for different species. This customized topography protects smaller organisms from larger predators and therefore maintains a degree of biodiversity otherwise impossible with flat or smooth boat bottoms that are easily colonized by non-native species. The design of these topographies makes use of statistical models that relate rugosity (magnitude of a surface's "bumpiness"), slope, dimensions of hillocks and valleys, and other parameters to anticipated ecological growth over time.

Fiber-reinforced polymer composites, commonly used in marine applications, offer several advantages for testing this hypothesis. Unlike steel or concrete, fiberglass is entirely resistant to corrosion in salt-water environments. New technologies of computational design and digital fabrication enable the production of highly differentiated topographies that would otherwise be very difficult to make; file-to-factory workflows translate digitally modeled geometry to robotic fabrication machines that can carve customized molds and formwork at a very high degree of complexity and precision. Furthermore, when fabricated in several layers with balsa wood cores or internal corrugated rib structures, composite materials have excellent structural capacity, which is further enhanced by double-curvature. In an opportune synthesis of performance criteria, these qualities of corrosion resistance, customizability, and structural strength render FRP an ideal material with which to test the hypothesis of an optimized ecological substrate.

4. PEDAGOGICAL FRAMEWORK

The primary vehicle for the Buoyant Ecologies research has been a series of three advanced architectural design studios at California College of the Arts (CCA) in San Francisco. These studios, led by Adam Marcus, Margaret Ikeda and Evan Jones, serve as a venue for speculative inquiry supported by outside expertise of ecologists and manufacturers, as well as empirical testing through full-scale prototypes of the optimized FRP substrate. The architecture studio becomes the primary site for the interdisciplinary feedbacks in which the designers, scientists, and industry partners each catalyze each other to consider ideas and strategies that otherwise may not emerge in a less collaborative framework.

The 2014 studio sited on San Francisco's Embarcadero was followed by two subsequent studios in 2015 and 2016, in which students designed speculative ecological research and education centers for Middle Harbor Shoreline Park, a public reserve located within the Port of Oakland. The Port constructed the park in the early 2000s as an amenity for the adjacent West Oakland neighborhood and as a prototype for how to integrate ecologically restored wetlands into the port's industrial infrastructure.[7] The shift to this particular site and context reflected a desire to situate this research within broader regional and national conversations on resilient coastlines as a defense against increasingly volatile climate patterns and rising sea levels.[8] It also began an ongoing partnership with the Port of Oakland, which as the fifth largest port in

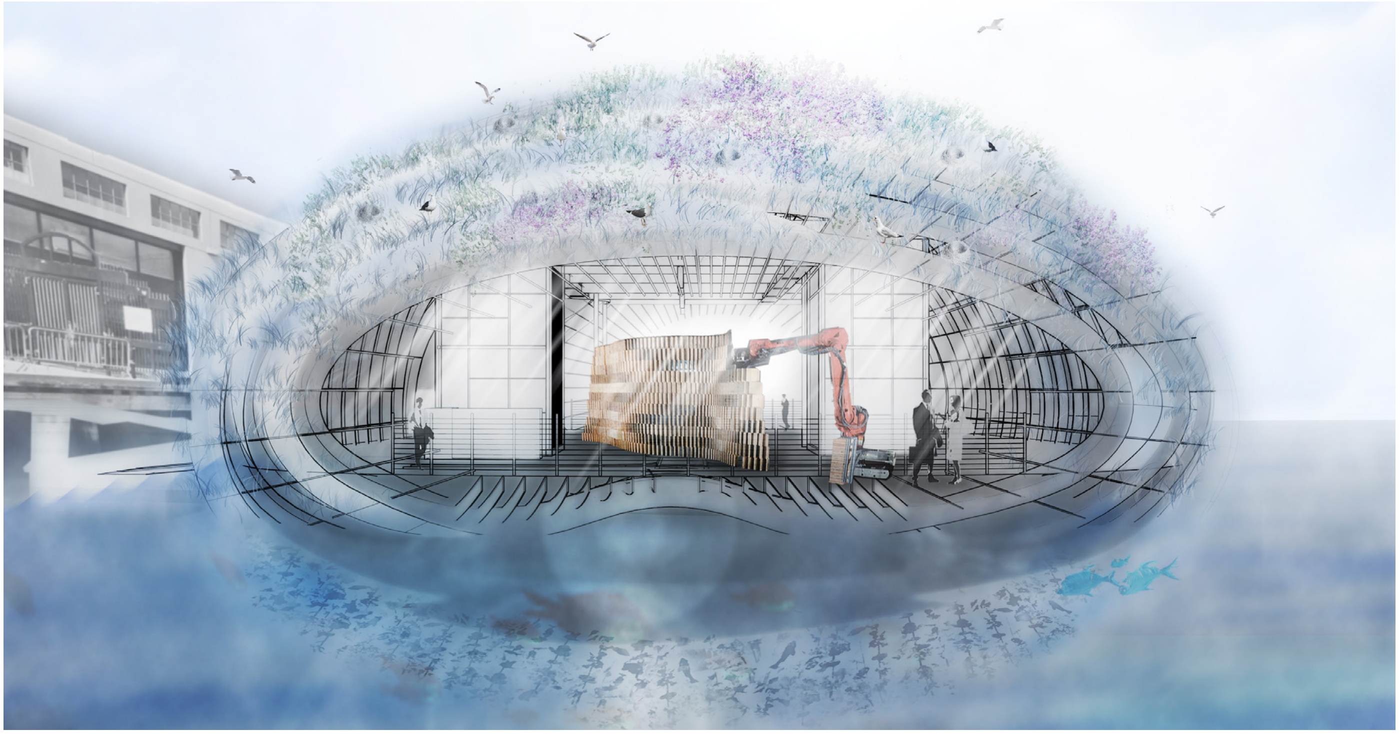


Figure 1: "Adaptive Creature," by Jill Chin-Han Chao, Hung-yi Chou, and Sanna Lee. This project from the first Buoyant Ecologies studio proposes a monocoque FRP structural shell that provides an ecological substrate both below and above the water. Its speculation about tidal habitats above the waterline inspired the Benthic Lab ecologists to consider additional ways for the substrate to perform beyond subsurface growth medium.

the United States and one of the most significant contributors to the Bay Area economy, recognizes the acute urgency of developing resilient strategies in response to sea level rise.

The studio structure maximized interaction with experts outside of the traditional boundaries of architectural academia. Visits to both Benthic Lab and Kreysler & Associates consisted not only of tours of the facilities but also interactive design charrettes in which students presented their in-progress proposals to the research partners. These visits were supplemented by regular video teleconference sessions in CCA's studio space to provide feedback at critical moments in the semester where ecological and material performance assumptions required validation or further explanation. As part of CCA's Integrated Building Design curriculum of comprehensive design studios, students also met regularly with professional consultants from practice: building energy experts, structural engineers, mechanical engineers, and facade consultants. Finally, all design reviews included representatives from each of the research partners—architects, ecologists, and fabricators—as well as other stakeholders such as the Port of Oakland and the San Francisco Bay Conservation and Development Commission (BCDC), the region's primary regulatory agency for coastal development.

5. INTERDISCIPLINARY FEEDBACKS

The structure of the Buoyant Ecologies studio was designed to encourage recursive feedback loops between designers, ecologists, and fabricators. These interactions ranged from predictable exchanges of knowledge and expertise to more unpredictable conversations and discoveries that opened up new directions for the research. The more conventional interactions typically consisted of architecture students presenting design ideas and ecologists offering pragmatic suggestions about how to improve the design and integration of the optimized substrate surfaces into the larger building proposal, or fabricators offering advice about material parameters and fabrication constraints. While critical for advancing the work, this type of knowledge exchange can be highly informative but is not truly *collaborative* in the sense that there is a bidirectional back-and-forth that generates new ideas or trajectories for the research. Rather, it was the unpredictable moments of interdisciplinary feedback—when pragmatic expertise and speculative design thinking began to inform each other—that proved essential for crafting the overall research trajectory.

Three examples of this interdisciplinary dynamic demonstrate pivotal moments in the project when design speculations initiated new directions for pragmatic and technical research. An early example occurred in the first studio, towards the middle of the semester as the architecture students began to develop their building proposals with drawings, models, and—importantly—perspective renderings of the outer hulls of their floating buildings. Architects often take their representational skills for granted, but the students' ability to visualize the corrugated and textured FRP topographies was revelatory for the Benthic Lab ecologists. Taking the cue from Kreysler that the composite shells can accommodate large spans, several of the schemes extended the FRP substrate above the waterline to form not only the vessel hull, but also walls and roof structure (Figure 1). Once manifest in visual form through renderings and study models, this notion of a fiberglass substrate on both bottom *and* top sparked a number of conversations

Figure 2: “Augmented Tides” by Rafael Berges and Jared Clifton. The project proposes a series of modular “tidal columns” that initiated broader discussions about potential integration of the optimized ecological substrate into wave attentuation and erosion control devices.

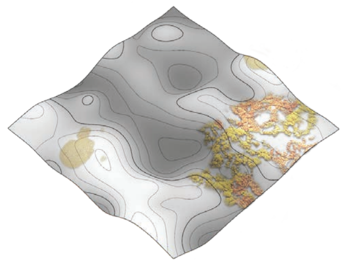
about how the top side could also be optimized to perform ecological functions. These include rainwater collection through carefully designed channels in the surface topography, pockets for plantings, and the notion of circulating salt water onto the roof to create artificial tidal wetlands on the exterior of the building. These ideas, which continued to inform student projects in subsequent studios, originated with the ecologists yet never would have emerged without the design speculations and visualizations produced by the architecture students.

Another example of this kind of interaction occurred in the second studio, as the focus of the research shifted to the Oakland site and larger questions of coastal resilience and sea level rise. As the students developed more sophisticated understanding of strategies of resilient design, the projects began to suggest a more integrated approach between fixed structures and buoyant structures, in which the buoyant structures began to perform ecologically at multiple scales. *Augmented Tides*, a proposal by Rafael Berges and Jared Clifton, consists of a U-shaped building that enclosed a courtyard-like lagoon populated with semi-buoyant “tidal columns” (Figure 2). These petri dish-like FRP composite structures are contoured to promote ecological growth of upside-down benthic organisms on the bottom side and also artificial tidal wetlands on the top side. The modular nature of the tidal columns—individual units, as opposed to a single continuous hulls of the first studio—sparked a conversation with Kreysler about the potentials of modular off-site construction. As the project developed and incorporated pragmatic constraints of fabrication, transport, and assembly, its higher level of resolution prompted the Benthic Lab ecologists to speculate about the columns’ function as wave attenuation devices to help prevent coastal erosion. Before this point, wave attenuation and erosion control was not a focus of the studio’s research, but the notion of networks of smaller buoyant structures as a strategy for preventing erosion has since emerged as a promising application for enhancing coastal resilience.

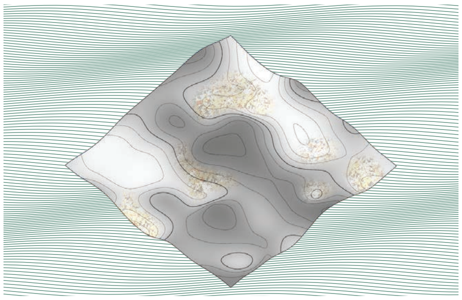
The third example, from the 2016 studio, demonstrates how the cumulative body of knowledge developed by previous students provides a foundation for subsequent studios to develop further. *SubOrdinate*, a project by Madeline Cunningham and Taylor Metcalf, proposes a “village” of small buoyant and semi-buoyant structures located just offshore of the park. The buildings are fabricated entirely of contoured FRP composite panels, which serve as structure, envelope, and as the optimized ecological substrate for marine habitats above and below the water. In designing the geometry of the FRP envelope, the students utilized an integrated parametric model to input the precise dimensional parameters provided by the ecologists and analyze this geometry according to specific metrics such as rugosity and slope. With input from the Benthic Lab team on statistical correlations between these metrics and the surface’s performance as an ecological growth substrate, the students were able to use the model to produce simulations of how these geometries would impact hydrodynamic flows, which correspond to delivery of nutrients and thus provide one way to predict growth over time (Figure 3). This process allowed them to digitally speculate in a highly informed way about the gradated communities of marine species that would emerge along the substrate over time. Although developed within the context of a speculative project, this kind of parametric process represents a significant breakthrough, as it demonstrated to the ecologists the relative ease by which one can develop a streamlined design-simulate-prototype-measure workflow.

6. FULL-SCALE PROTOTYPING & TESTING

The studio curriculum incorporated a series of full-scale prototyping experiments that have provided an empirical basis for the speculative explorations at the building scale. Just as the visionary thinking of the architecture students provoked the Benthic Lab and Kreysler collaborators to think about pragmatic solutions in new ways, the process also occurred in reverse: the pragmatic lessons of fabricating and testing a prototype at full-scale inspired new possibilities for speculation grounded in material and ecological performance.



LOW RUGOSITY
Above



LOW RUGOSITY
Below

TAXONOMY

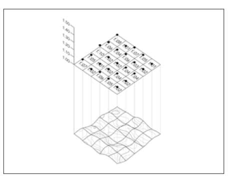
Above
Algae:
-Green Algae
-Red Algae
Bacteria:
-Blue-Green Aglae
Lichen:
-Crustose Lichen
-Foliose Lichen
-Fruticose Lichen

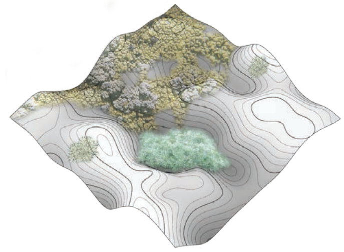
Below
Algae:
Brown Algae
Red Algae
Invertibrates:
Bryozoans
Tunicates

DATA

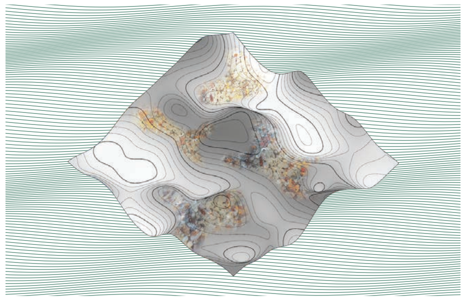
Peak Height = 1′
Dimensions = 6′ x 6′

Area = 37.68 sq ft
Rugosity = 1.05
Slope = .54°
Aspect = 122.77°





MEDIUM RUGOSITY
Above



MEDIUM RUGOSITY
Below

TAXONOMY

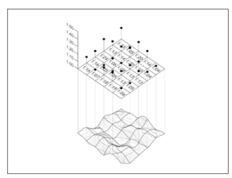
Above
Plantae:
-Abronia
-Artemisia
-Atriplex
-Lupinus

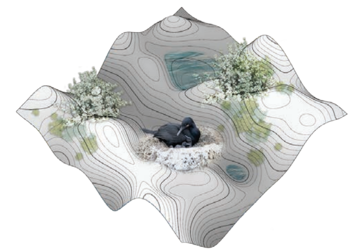
Below
Invertibrates:
-Bryozoans
-Crabs
-Hydroids
-Limbets
-Polychaetes
-Sponges
-Nudubranchs
-Tunicates

DATA

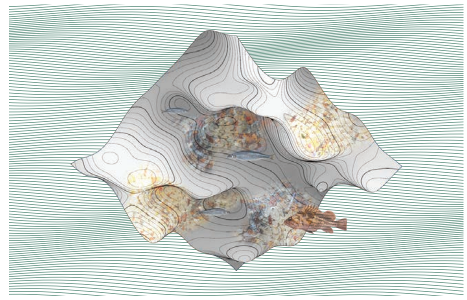
Peak Height = 2′
Dimensions = 6′ x 6′

Area = 42.10 sq ft
Rugosity = 1.17
Slope = 1.04°
Aspect = 141.25°





HIGH RUGOSITY
Above



HIGH RUGOSITY
Below

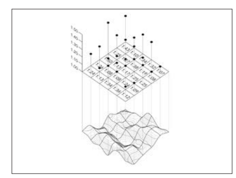
TAXONOMY
Above
Birds:
-Cormorant
-Gull
-Loon
-Tern
-Heron

Below
Fish:
-Herring
-Rock Fish
-Top Smelt
-Pipe Fish

DATA

Peak Height = 3′
Dimensions = 6′ x 6′

Area = 48.27 sq ft
Rugosity = 1.34
Slope = 1.56°
Aspect = 154.53°



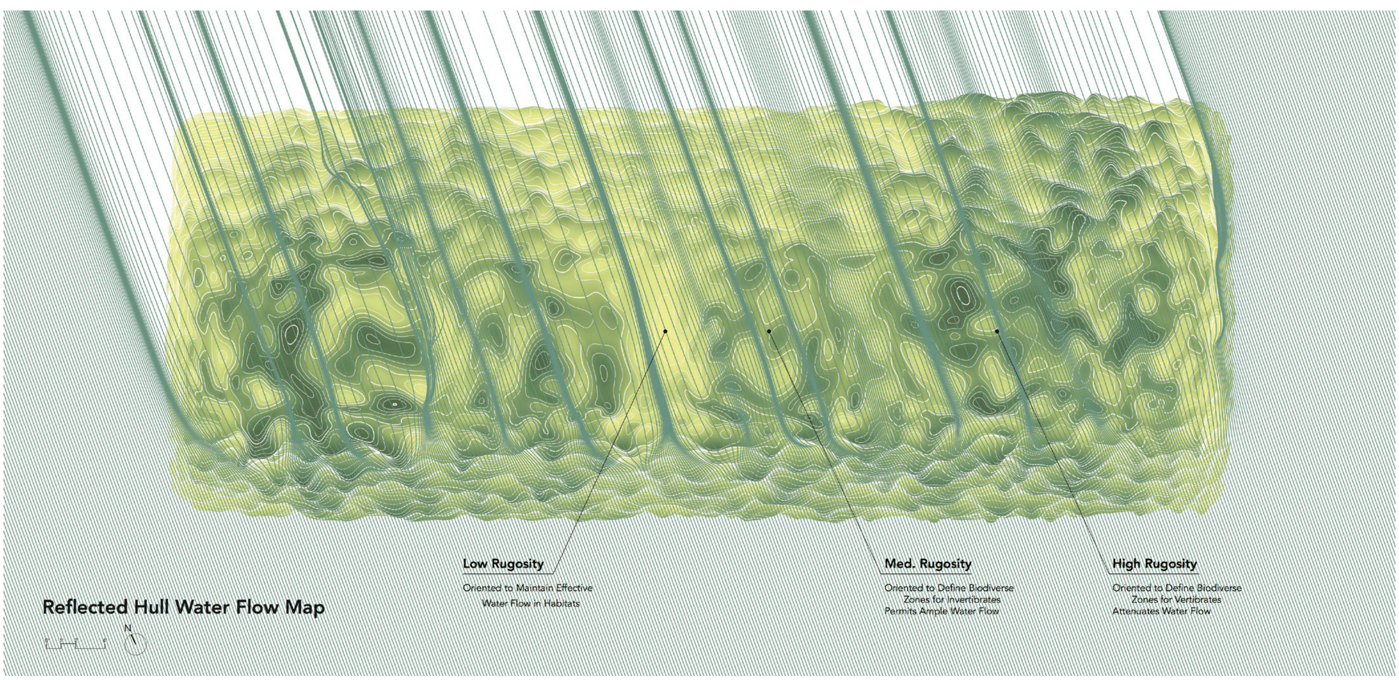
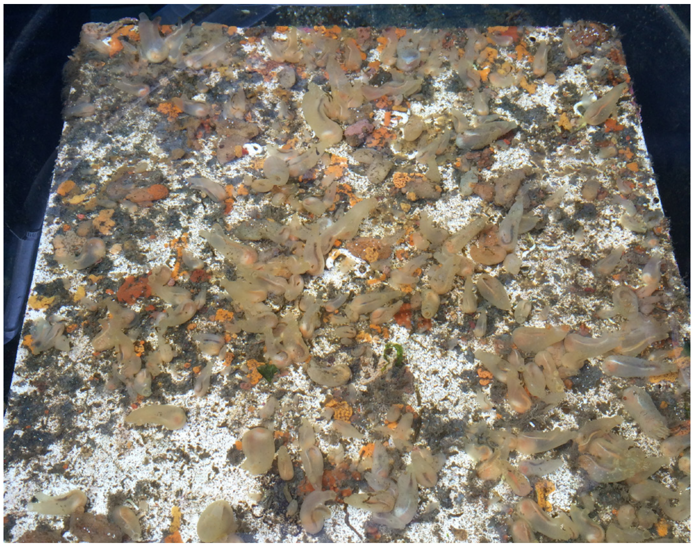


Figure 3: “SubOrdinate” by Madeline Cunningham and Taylor Metcalf. The project utilized an integrated, parametric model that incorporated quantitative inputs from the ecologists (above) and generated a simulation of the hydrodynamic flows that would be produced by the variable geometries (below).



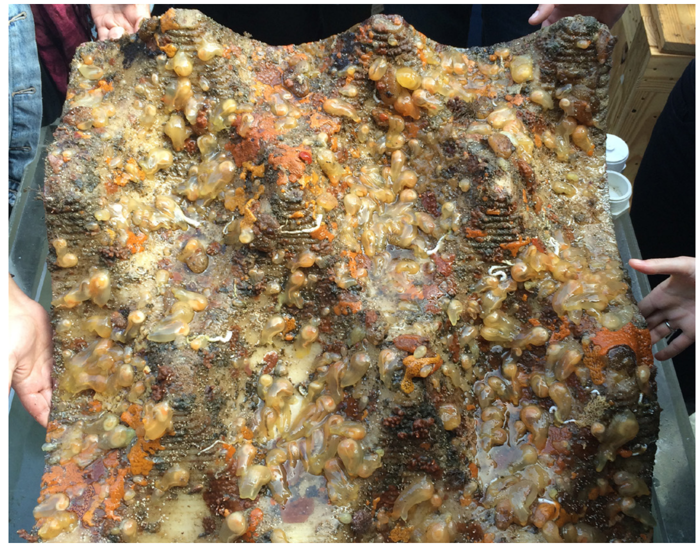


Figure 4: The above full-scale prototypes were submersed upside-down in Monterey Bay for twelve weeks to test relationship between geometry and colonization of species. Comparison of a flat control substrate (left) with a rugose substrate that incorporates variable hillocks and valleys demonstrates proof-of-concept that gradated habitats of invertebrates can be modulated with differentiated geometries.

To date, project partner Kreysler & Associates has produced three sets of 24” by 24” prototypes, all of which have been installed underwater for monitoring and evaluation by the Benthic Lab team. The first set consisted of entirely arbitrary geometries, sampled from the speculative building designs of the 2014 studio. Although uninformed by performative metrics like rugosity and slope, these prototypes were crucial for establishing “proof-of-concept” confirmation that rugose geometries foster gradated habitats of invertebrates that are more diverse than those found on flat, undifferentiated surfaces (Figure 4). Subsequent prototypes incorporated observations about the substrate’s performance into a set of typologies for the optimized substrate based on simple, repetitive geometries. These forms—informally dubbed “pyramids,” “juicers,” “keels”—may at first seem arbitrary and whimsical, but they reflect precise input from the ecologists regarding geometry, dimensions, and slopes for the FRP surfaces (Figure 5). These formal and performative logics then feed back into the students’ design workflow, often inspiring and catalyzing the development of formal strategies at a larger scale.

A critical factor in the prototyping process has been the involvement of Daniel Gossard, a graduate Masters student in the Benthic Lab program who has aligned his thesis research with that of the Buoyant Ecologies project. Daniel’s expertise as both an ecologist and a diver (he conducts regular dives to monitor the performance of the ecological substrates) has proven enormously important in solidifying the link between ecological performance and architectural design. In the most recent studio, this student-to-student interaction between ecologist and architect has greatly streamlined and enhanced the feedback between disciplines.

7. CONCLUSIONS & NEXT STEPS

With the encouraging results of the initial prototypes, the project partners have commenced work on the next phase of the research: constructing a larger-scale prototype to be deployed at Middle Harbor Shoreline Park in the Port of Oakland as a testing lab and public demonstration project. The “Float Lab,” a small vessel with connection points on the underside to attach modular substrate prototypes, will serve several purposes. It will facilitate ongoing testing of the substrate geometries, as well as other types of growing mediums, such as “vertical structures” that mimic the submerged roots of mangrove forests. With a small inhabitable interior space, the vessel will also serve as a prototypical “scale model” of a floating building and encourage conversation about this typology as a potential strategy for resilient design. Finally, as a complement to the Park’s mission as a didactic, educational resource, the Float Lab will serve as a pedagogical tool, teaching visitors and increasing public awareness about the challenges of rising sea levels.

Although still in the early phases, this project owes its initial success and momentum to the pedagogical structure of the architecture studios that serve as the primary venue for the research. By incorporating Benthic Lab’s scientific knowledge and Kreysler & Associate’s material know-how, the collaborative structure triggered a recursive set of feedback loops that transcend the conventional, false binary distinction between visionary thinking and practical knowledge, instead allowing the two to inform each other. As architects work to develop compelling and robust strategies for resilient shorelines, it is critical to develop thoughtful and productive ways of integrating extra-disciplinary expertise into the design process. The Buoyant Ecologies project points to one model for taking on complex, wicked problems such as climate change and sea level rise, which demand a synthetic integration of academia *and* industry, design *and* research, speculation *and* pragmatism.

ACKNOWLEDGEMENTS

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Marine Ecology Partner: Benthic Lab / Moss Landing Marine Laboratories — John Oliver, Kamille Hammerstrom, Dan Gossard

Fabrication Partner: Kreysler & Associates — Bill Kreysler, Josh Zabel, Michelle Aquino

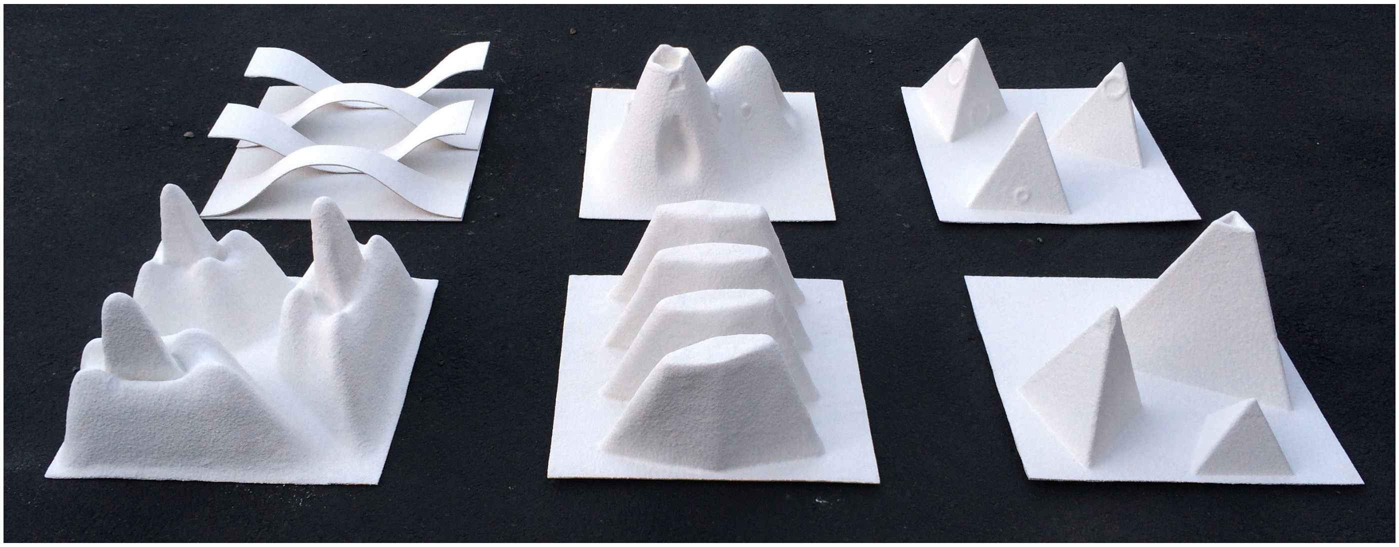

Figure 5: The second round of full-scale FRP substrate prototypes incorporated lessons from earlier tests. The geometric typologies are based on precise dimensional and slope metrics provided by the Benthic Lab ecologists.

Project Sponsors: Autodesk Pier 9 Workshop, Port of Oakland, Private Donors

CCA Buoyant Ecologies Studio, 2014: Hayfa Al-Gwaiz, Behnaz Banishahabadi, Welbert Bonilla, Jill Chin-Han Chao, Hung-yi Chou, Tyler Jones-Powell, Sanna Lee, Mikaela Leo, Maryam Nassajian, Yasmine Orozco, Melissa Perkinson, Jude Simon, Blake Stevenson, Dustin Tisdale

CCA Buoyant Ecologies Studio, 2015: Rafael Berges, Trishala Umesh Chandra, Kuan-Lun Chen, Jared Clifton, Keith Edwards, Kenneth Hu, Vaama Joshi, Susan Lopez, Shirin Monshipouri, Betty Nip, Min Joo Noh, Omar Soliman, Susan Wing, Ka Ki Yam

CCA Buoyant Ecologies Studio, 2016: Fernanda Bernardes, Gina Bugiada, Bryany Burke, Madeline Cunningham, Taylor Metcalf, Mrnalini Mills-Raghavan, Georine Pierre, Stephany Rattner, Carlos Sabogal, Arash Sedaghatkamal, Nicole Van Malder

ENDNOTES

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3. Lindsey, Rebecca. "Climate Change: Global Sea Level." Accessed January 29, 2017. https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

4. For documentation of the 2014 Buoyant Ecologies studio, see Ikeda, Margaret, Evan Jones, and Adam Marcus, *Buoyant Ecologies: New Visions for San Francisco's Waterfront* (2015).

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6. For an overview of the impact of benthic organisms on marine ecosystems, see Gili, Josep-Maria and Rafel Coma, "Benthic suspension feeders: their paramount role in littoral marine food webs," *Trends in Ecology & Evolution* 13:8 (August 1998): 316-321.

7. For an overview of the history of the site and design of Middle Harbor Shoreline Park, see David Gates & Associates and Thurston Design Group, *Middle Harbor Shoreline Park Master Plan* (1999).

8. Resilience can best be defined as the elastic ability to return to stability after the shock of a crisis or natural disaster. Conversations about architecture's role in constructing resilient cities increased in the aftermath of Hurricane Sandy in 2012, when cities began to recognize increasing vulnerability to the effects of climate change. For a general overview of principles of resilient design, see Rachel Minnery, "Resilience to Adaptation," *Architect* (August 4, 2015), accessed January 29, 2016, http://www.architectmagazine.com/aia-architect/aiafeature/resilience-to-adaptation_o

By Proxy: Design Problems and Collaborative Inquiry

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Running parallel with the increase in partnered research initiatives in the fields of technology, medicine, and engineering, collaborations between private sector commercial or research organizations and academia are on the rise in architecture. There has been a recognition particularly in the last ten years of the value of incorporating design thinking into problem solving across scales and industries. From focused material investigations to long-term strategic planning, those outside of academia are looking to architects and spatial designers to leverage their approaches and processes to address real-world issues faced by communities, organizations, and businesses. Universities use these partnerships to fund research, offset capital expenses, and expand their influence. But these partnered research initiatives do not come without costs. The responsibility for companies and organizations is to see a return on their investment. Consequently, for universities, the academic freedom and maintaining of a clear pedagogy can be met with pushback. In addition, project goals and values do not always align, and expectations between partners can vary.

This paper examines a number of strategies that address the inherent tension in partnered research-design projects by reconfiguring stated problems into proxy inquiries. Proxies, as stand-ins for another - a person, an organization, an action or a process - allow for existing problems to be reconstructed into pedagogical ones - they allow for scales to be shifted and they generate holistic outcomes in the truncated duration of a semester, rather than offer piecemeal results. Proxies offer a methodology for accepting the constraints of partnered research as a way of expanding design inquiry, while remaining grounded in problems fundamental to architecture and design. More than just a substitute, proxies transmit agency.

Outlined in the paper are findings from the Proxy Series, which began in 2007 as a set of research-based academic inquiries focused on the exploration of emerging technologies and their reshaping of 1) design theory, 2) design process, and 3) design production. Conducted through studios, seminars, and independent research, each inquiry investigated a discrete set of issues spanning these three areas. While each is constructed to address a specific design problem within a pedagogical framework, the imposition of extra-academic considerations allowed for the pursuit of production techniques, materials research, and software experimentation, while working with partners and collaborators outside of the design discipline. As such, proxies offered an alternative formulation of the design life-cycle - one that emerged and evolved beyond conventional forms of practice or current problem-solving approaches, while mirroring the aspirations of the partnered research model itself.

THE REAL & THE SIMULATED

Design education takes many approaches toward the design of the *design problem*. For architectural education, the vast majority of these didactic problems work in the mode of approximation, in which the design problem is constructed as simplified versions of *actual* architectural projects. This happens either by truncating the scope of the project or by reducing the number of variables one may expect to encounter in the process of designing a building or structure. In both cases, the set of information considered is limited and their role in the design process constrained. This effort recognizes the need to make the studio problem manageable for students within the span of a single semester, and calibrated to match the knowledge and experience level of the students involved.

However, the studio problem is not just a simplified architectural project, but one which is supplemented as well. By augmenting projects with specific practical or theoretical considerations, these projects shift their focus to align with a particular pedagogical stance. This supplemental content is often directed toward expanding a

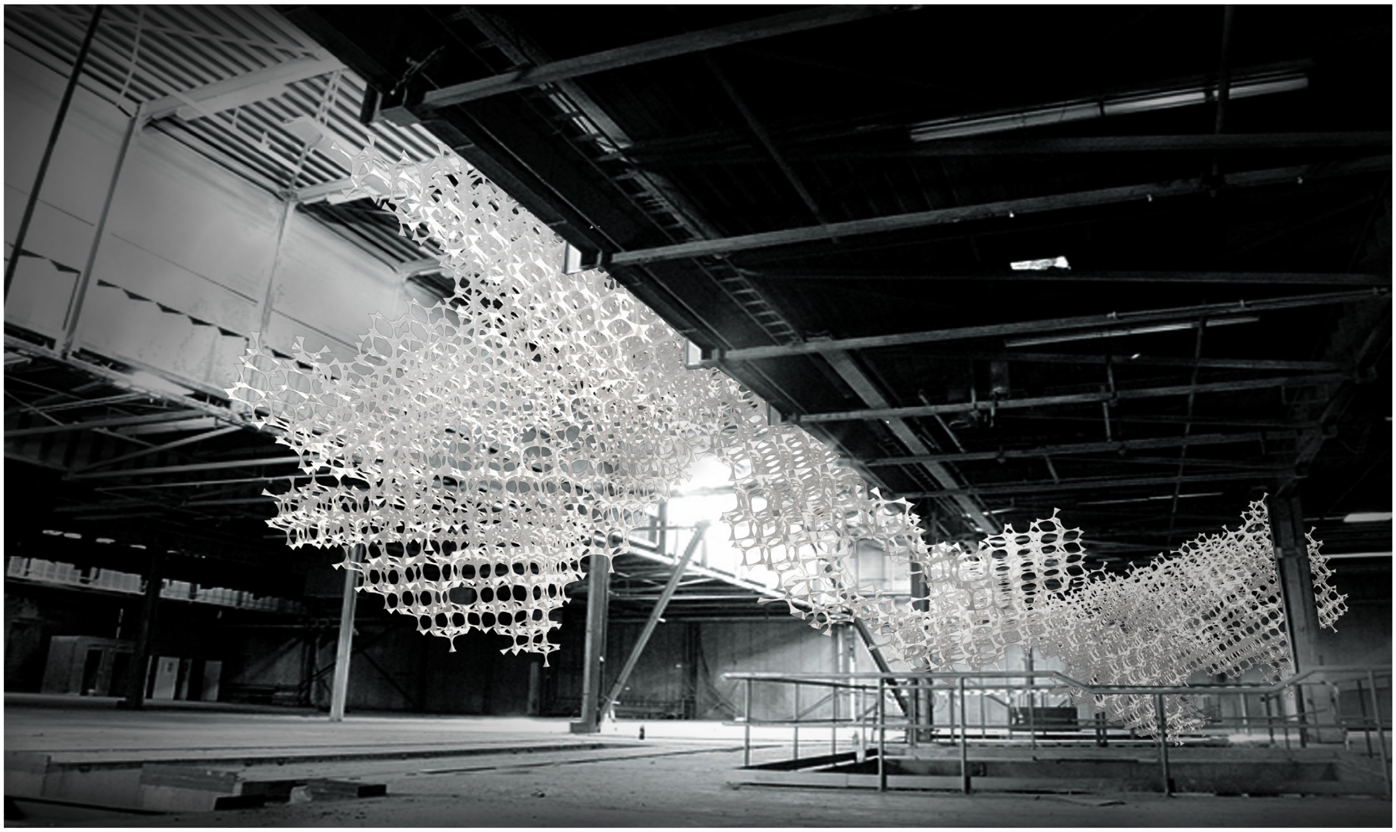


Figure 01: Proxy No. 06 (Zersetzung Wolke) | Installation Proposal

student's capacity to address the design problem with criticality. In effect, supplementation adds another domain of information onto the simplified problem - one that simulates many of the theoretical propositions that operate within architecture as a discipline. These are often implemented in an explicit and programmed manner, skewing the embedded nature of these issues in the practice of architectural design.

The simplified and supplemented problematization approach combines two domains of information, *the real* and *the simulated*. This combination is effective in that it both grounds the design problem in a shared and familiar context, while introducing complications or considerations that encourage students to engage the design process in a more expansive, projective manner. This approach ties theory with practice to develop critical design solutions that move beyond the everyday.

There is also an inherent flexibility in this approach, by foregrounding certain considerations while allowing others to recede. Within this general outline for the architectural design problem, a wide variety of pedagogical stances can be taken that retain the advantages mentioned above. And, while this approach may work well in the academy, and particularly in design studios, the design problem is being increasingly shaped by those who are not fully embedded in academia. This is a product of a number of trends, the most salient being the changing makeup of faculty and a move toward academic and commercial partnerships.

The makeup of university faculty has steadily moved away from full-time academics.[1] This is especially the case in the design disciplines, where research funding is comparatively low and curricula often incorporate professional development courses. This translates to architecture schools relying on an average of 66% adjunct faculty.[2] These instructors are often practitioners, operating in adjacent fields or as instructors at multiple institutions. Contingent faculty can bring a more transgressive view of education which exploits the gaps between practice and education - being situated in both domains generates a perspective that can offer alternative pedagogical approaches. However, the unpredictability in course assignments, schedules, and resources make developing pedagogical approaches that take advantage of these gaps difficult to achieve consistency.

Commercial, governmental, and institutional partnerships, a staple in many of the STEM and medical disciplines, have expanded within the architecture and design disciplines. This trend has fostered collaborations with non-academic entities on partnered design problems. A survey of partnered research projects at the Rhode Island School of Design for the 2015/16 academic year included collaborations with Lego, Nike, NASA, Samsung, and Textron Aviation, among others.

Partnered studios and design projects challenge the effectiveness of a simplified and supplemented approach to crafting the design problem. The difficulty in establishing shared goals and simultaneously creating a learning environment within this project context, places pressure on the formation of design problems that retain academic integrity. They

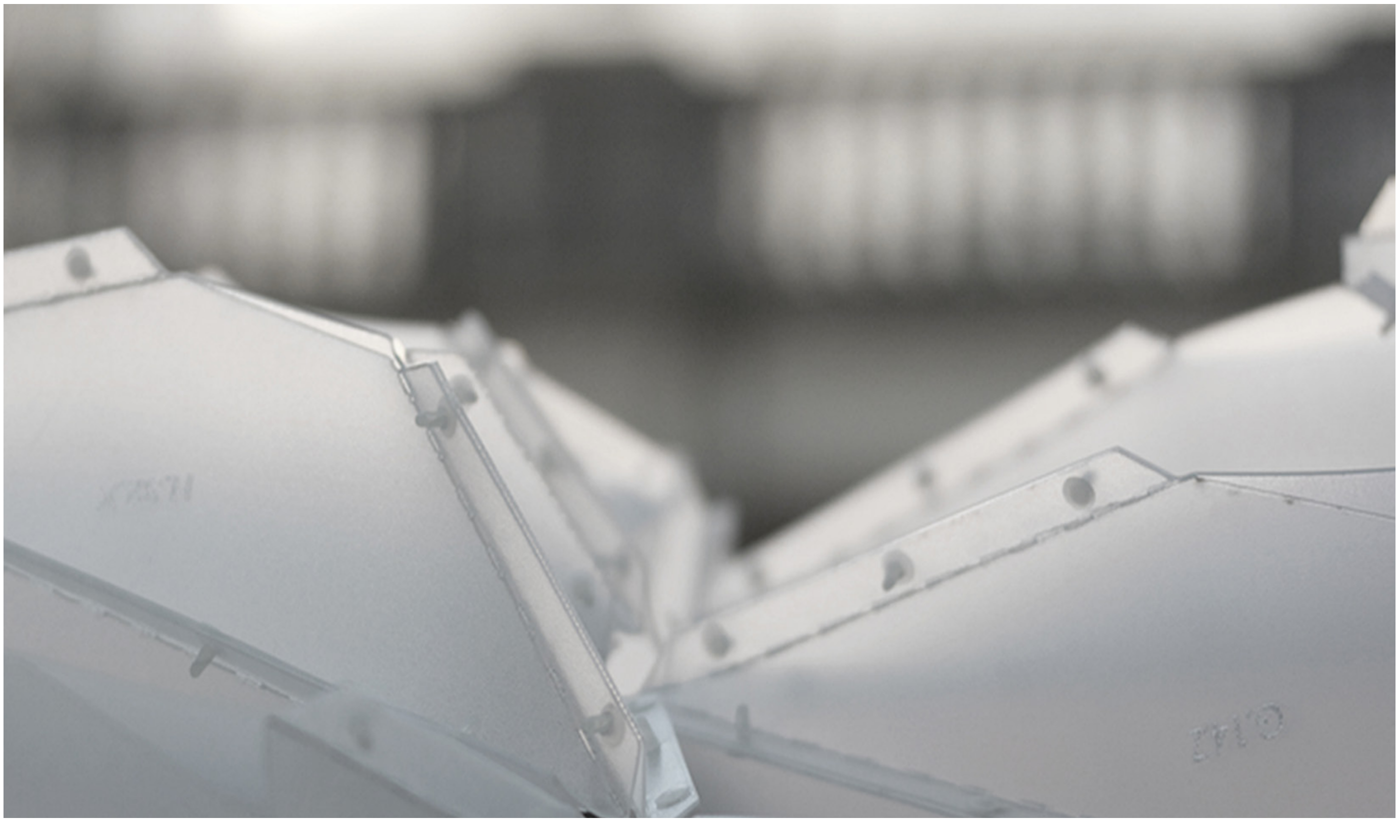


Figure 02: Proxy No. 13 (4111 Montrose) | University of Texas, Austin + Beta-field + Montrose Galleries | Course: Compu-tectonics

also complicate the way in which information is valued, mobilized, and utilized between domains.

PROXIES

A traditional progression of studio design problems may also be understood through a gradient from the didactic towards the real-world and open-ended. In other words, students earlier on in their academic careers are more likely to be given highly structured and abstract design problems that operate within a limited set of conditions in order to build fundamental techniques and skills, while also reinforcing design principles - the arguments for what is or is not fundamental and what should or should not be design principles notwithstanding. In real-world design problems, there is an effort, or at the very least, a perception that these design problems address the major problems one may face in professional design practice. This includes many of the cultural, regulatory, and physical considerations that are taken into account when designing projects are intended to be built.

This progression is challenged through partnered projects and non-traditional faculty make-up, where the mixture of agendas and actors involved creates a folded, rather than blended collection of information sets. The correlation between the real and the simulated is inconsistent and at times ill-fitting. While these descriptions may be generalistic and reductive, they match the insights of many of my colleagues and my own experiences as an educator. And it is from these insights and experiences that the Proxy Series of design problems originated.

Initiated in 2007, the Proxy Series is a set of partnered explorations that occupy territories of both academia and practice. Proxies are stand-ins for another - a person, an organization, an action, or a process. Proxies are not simulations, they do not require simplification or supplementations. They are holistic projects defined by the constraints shared by both pedagogical and practical concerns. More than just a substitute, proxies transmit agency. The goal of the Proxy projects is to set forth a series-based exploration of spatial artifacts that complete the design-to-fabrication life-cycle.3 They simultaneously examine the challenges and considerations that arise as one addresses deeply pedagogical and experiential design problems with those that are material and physical.

The first project, Proxy No. 01 Hooke's Continuous Structure started as a way of learning how to create an autodidactic design problem. That design problem quickly lead to an expanded set of projects, Proxies No.02 - 06, which positioned this initial question into a collaborative investigation through full-scale implementation (fig. 01).

In each case, a few underlying questions were quickly established that were key to all projects in the series. Each consideration is built from a more fundamental question of how collaborative/partnered projects span the divide from initial research to full-scale implementation. One of the issues in spanning that breadth of inquiry lies in how information is incorporated, utilized, and manifested spatially. Though that question could be understood as encompassing multiple aspects of

Figure 03: Proxy No. 08 (Serpentibus Modularis) | University of Virginia & Beta-field | Course: Computational & Material Practices

design, the Proxy Series instrumentalized this question within three information operations - workflows, continuities, and residues - which spanned both academia and professional practice and which could be addressed in multiple avenues of inquiry, whether collaborative or not.

Workflows

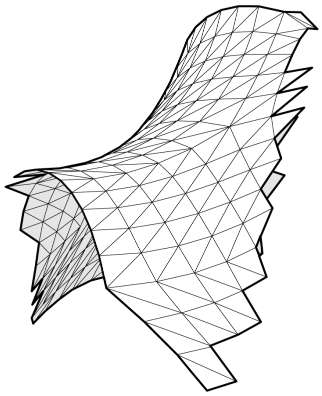
The first consideration built into the Proxy Series is that of information transfer. Transference in design is the active directing of information from one medium to another. A more common way of understanding this is through the term workflow. Workflows are already embedded into all forms of design practice, though they are not always explicit considerations within the design process. The term today refers more to digital design methodologies and practices, but when thought of more broadly as transference the idea permeates through multiple cultural, disciplinary, and technical contexts.

In transference, an understanding of how and what information is manipulated is crucial. Workflows, like all other constructed systems can be crafted to perform in certain ways. Workflows are chains of information transfer, which can be structured in either linear, networked, or recursive ways; and often times, in combinations of structures. Workflow structures are procedural in nature as such they too are embedded in any design problem. These procedural concerns have implications on all aspects of the design and manufacturing process. They impact where and how a designer might intervene within that process. Workflow, in many ways, is the superstructure for any design and manufacturing process. While disparate agendas across project partners may be practically or philosophically irreconcilable, procedures are not. The goal of any protocol is in fact to navigate the various systems in an assemblage. Protocols are only effective when they create a way for bridging systems - protocols that cannot be shared are not protocols by definition.

For the Proxy Series, workflow does not end at representations or prototypes, but at full-scale implementations. The Proxy Series is concerned with the crafting of procedures that take on the transfer of information across systems and materials as integral to any design problem (fig. 02). This approach creates an instructional environment, where creating reciprocity between a variety of platforms of exploration, development, and production are essential. Implicit in the concept of transference in technology is that of the "technical ensemble".4 The technical ensemble, as defined by Leroi-Gourhan and contextualized in digital media by Felix Guattari, encompasses the systems through which technical objects are defined; and, it is within this concept of design production as the technological, that the Proxy Series operates.

Proxy No. 08 was the first in a series that took this approach with students (fig. 03). This project was conducted with students from the University of Virginia through a research partnership with Beta-field. The project began by assessing the overlaps in how each entity had developed practices for transference, which were found to be common for material production in the AEC industry and architectural education.

These overlaps fell into three categories. The first was transference through technique. These, for example, included a limited set of manufacturing techniques that corresponded with the university's available equipment and the set of material compositions and typologies which could be used with those techniques. The second was transference through platform. This examined what technologies could be used as a host platform for the project. Additionally, we examined what support and skill base the students and practitioners involved shared. In this case, we settled on the use of Rhinoceros as our modeling platform, incorporating plug-ins and scripted components to generate, analyze and test proposals; and rationalize, organize, and prepare models for manufacture. The third was transference through material. This for example included the physical limitations of the facilities and its participants, and how they related to the scale of the project, the material



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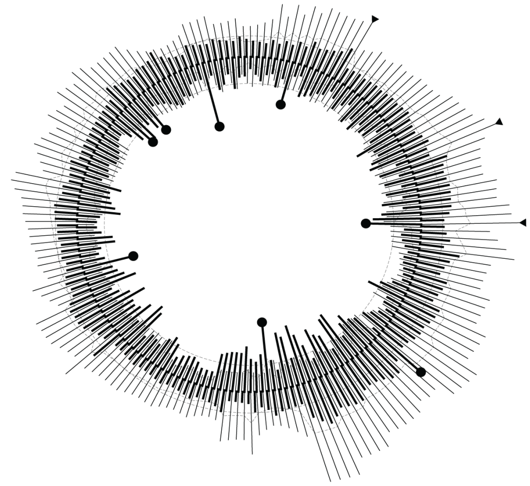

Figure 04: Proxy No. 10 (12% Pavilion) | University of Virginia + Beta-field + AIA National Headquarters | Research Partnership

characteristics, and the assembly process - all within the question of information transfer.

All three considerations shaped the design of the project work-flow, and they were not all a priori conditions. Rather, we started by slowly building the design process, incorporating new constraints as questions of what we should and could do, emerged. This limited bottom-up approach proved to be very useful in instructing students how they might construct their own design process. It also allowed room for each student's strengths to be revealed and leveraged.

CONTINUITIES

The academic design problem, in particular those developed for studio environments, translate information through representation. Translation is the substitution of one set of media specific data with another set, in an effort to traverse media. The advantages of a primarily representational model of design inquiry are clear. *Scale:* representational systems allow for changes in the size and complexity of production, where smaller, reductive artifacts can stand-in for full-scale built environments. *Conventions:* representational conventions off-load the responsibility of back-end translation onto the construction and manufacturing industry. And, *Fragmentation*: representations by definition that generate partial descriptions of spatial objects. A clearer, fuller understanding of a spatial object is achieved through an accumulation of representations. Representations offer a logic for division. For practiced designers, the ability to traverse the discontinuity between representations and actual spaces becomes second nature, creating a tight correlation between these two mediums

However, for students who have not had enough experience with conventional modes of design representation, the immediacy that educators and practitioners enjoy is replaced by uncertainty. The Proxy Series employs a non-representational or "information continuity" approach to the design problem.[5] Here, information translation becomes incorporated into the process of information transference. This creates variations on the representation to manufacturing relationship, where representation is used to access information, but not necessarily to translate it. Another way of thinking of this is that the role of representation to convey information on a technical level is abolished. The "file-to-fabrication" model of translation is expanded to cover all aspects of the design process life-cycle.[6] This is increasingly the case as regulatory and legislative limitations on information-rich documentation, such as Building Information Modeling (BIM) are beginning to catch-up with decades old technological advances. The same can be said for complex geometries, responsive materials, computer-aided manufacturing and assembly, and the preformative challenges presented by sustainability

Design-build is one avenue that challenges the predominance of representation; however, financial constraints and academic schedules make widespread adoption rare. They are difficult to complete in an academic semester and they must be funded at relatively high levels for design schools. The Proxy Series circumvents many of these considerations. By limiting the size, functions, and locations of these projects, where many of the regulatory and preformative considerations building must adhere to are irrelevant. As these considerations are allowed to fall away, others such as structure, material effects, formal and spatial composition, and other environmental performances can be retained and even highlighted; and the role of representation is allowed to take on new significance. This is the case in Proxy No. 10, a partnered project with the American Institute of Architects, where representations were used to communicate much of the data typically relegated to Building Information Modeling files (fig. 04).

RESIDUES:

Bruno Latour's assertion that all translations of information require transformation is one that is prophetic for the architecture and design disciplines.[7] Advancements in digital production do not change this fact, they only bring its existence to the forefront of inquiry. Working in a representational mode affords an understanding of one's own work inasmuch the ways one understands how representations are translated and transformed into physical/material space. The discrepancies inherent in any representational system are mitigated by the conventions of practice. For architecture that means regulatory, manufacturing, construction, and engineering industries. This forms a threshold between architectural representation and architectural production, which often defines the boundaries for the academic design problem. It also establishes the terms under which solutions to that problem are evaluated - its representational coherence, legibility, and correlation to a potential built environment.

But, as Lev Manovich describes, "information processes often leaves material residues."[8] Those discrepancies or opportunities to design transformation are left out of the design problem, but their residues as they manifest in the built environment is not. This is particularly clear when working with projects partners outside of academia. When building full-scale, the discrepancies between representation and spatial manifestation are brought into the design problem. This opens new ways to explore information translation and its effect on material formation.

The Proxy Series, along with other design-to-manufacture academic research, uses transformations in information through media as a core design issue in the post-digital age. Exploring material computations, which combine embedded and applied computation through full-scale constructions is one such approach. Proxy No. 16 is an example where the digital approximation of a design solution only describes half of the information required to complete the project (fig. 05). Here, formal geometries are produced as continuous curvatures formed through the physical properties of the materials in use, under loads, and at scale.

Material computations - and other like-minded investigations - are only possible through projects that engage in full-scale design problems. They, in and of themselves, can reveal alternative organizations for inquiry such as the investigation of multiple domains of information simultaneously or the reversal of the representation to construction relationship. In each case, key insights come from confronting the entire process of information translation through all phases and scales of the project's design life-cycle.

CONCLUSIONS:

As with the increase in partnered research initiatives in the fields of technology, medicine, and engineering, collaborations between private sector commercial or research organizations and academia are on the rise in architecture as well as other design disciplines. There has been a recognition, particularly in the last ten years,, of the value of incorporating design thinking into problem solving across scales. From focused material investigations to long-term strategic planning, those outside of academia are looking to architects and spatial designers to leverage their approaches and processes to address real-world issues faced by communities, organizations, and businesses alike.

Universities use these partnerships to fund research, offset capital expenses and expand their influence. But these partnered research initiatives do not come without costs. The responsibility for companies and organizations is to see a return on their investment. For universities, academic freedom and maintaining a clear pedagogy can be met with pushback. Project goals and values do not always align, and expectations between partners can vary.

As such, their incorporation into any curricula is meet with questions. What advantages do partnered projects lead by contingent faculty produce? How does design education incorporate more progressive pedagogical agendas? How do we produce solutions that have a more immediate and meaningful impact on the built environment?

The Proxy Series was designed to operate within, parallel to, and outside of academia, but retain its core experimental and instructional value. As both a framework for exploration and collaboration, the Proxy Series is meant to reconsider the design problem in a way that recognizes changes in an academic environment. While the Proxy Series does not claim to answer these questions, those questions have shaped its development. More importantly those questions are becoming crucial to design education, both in terms of outside pressures and disciplinary relevance. They are questions that are influencing not only this series of collaborative projects, but ones throughout a diverse set of institutions and organizations globally.

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Proxy No. 06: Zersetzung Wolke: Michael Leighton Beaman + Thomas Gibbons

Proxy No. 08: Serpentibus Modularis: Michael Leighton Beaman, Zaneta Hong, Lawrence Lazarides, Emma Gisiger, Feng Wang, Brad Schuck, Ernesto Rementilla

Proxy No. 10: 12% Pavillion: Michael Leighton Beaman, Zaneta Hong, Lawrence Lazarides

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Proxy No. 16: Surface Assemblies: Michael Leighton Beaman, Zaneta Hong, Ru Chen, Iok Wong

Figure 05: Proxy No. 16 (Surface Assemblies) | Rhode Island School of Design + Beta-field | Partnered Research

Hypermodels: An Exploration of New Media Environments and Expansive Representation of Architecture

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With the advent of new digital media technologies offering immersive virtual environments have emerged new modes of architectural representation. How, in turn, can these technologies shape the less visible, and visual, aspects of architectural production? This paper considers such digital, immersive technologies as Mixed, Virtual, and Augmented Reality within the historical and theoretical context of digital media to better understand their function in charting a frontier for the three dimensional representation of architecture. I propose the notion of the *hypermodel*, a "hypertext version" of digital models that contains and "opens up" to more than the physical parts of a building. Hypermodel is a connector of digital space and the physical world—represented via multiple forms of media—revealing the temporal expanse and informational depth of the virtual beyond the bounds of an architectural artifact. In this sense, the new medium also hints at and allows for novel collaborative methods. The new language of design and communication at work in the mixed reality medium is itself interconnected—it reflects and reinforces the inter-disciplinary and inter-media nature of architectural production today.

This paper establishes a conceptual framework and projects a methodology for future applications of such a hypermodel. To begin, it is helpful to better understand the context of and define "digital media" and "new media," as they are ubiquitous yet elusive terms. I will do this through a brief overview of the terms as employed in media studies and in contemporary discourse, and by identifying the most salient aspects that characterize the "new" in digital media. Then, I will discuss the relationship between new media and older media through the notion of "remediation" and, finally, explore new media's relevance to and adoption in architectural production. I will argue that digital 3D models endowed with new media capabilities, what I refer to as hypermodels, leverage the potential of the technology. By way of discussing several examples of recent collaborative applications of virtual environments in the building industry, I will follow with a closer reading of a digital reconstruction project of an architectural heritage site. The complexities of this and similar sites will exhibit the need for a hypermodel—a representational strategy that integrates immersive and heterogeneous media in relaying the tangible as well as the intangible aspects of architectural production.

WHY BEGIN WITH MEDIA? (WHAT IS NEW MEDIA ANYWAY?)

Broadly speaking, media refers to the means and channels of communication, and its genealogy includes oral histories, papyrus print, press print, and electronic dissemination in various forms. As an academic discipline, media studies has a relatively short but prolific past, with its scope and focus varied among distinct geographies. In the U.S., starting as early as the 1960s, media studies have resided primarily in mass communication departments and maintained close ties with film and TV production. In contemporary discourse, the term "new media" refers to the computerized means of communication and embraces anything within the digital realm, from mobile phones to virtual reality. The seminal digital media theorist Janet Murray explains the need for and the tendency toward such a broad sweeping and generic grouping. In her book, *Inventing the Medium: Principles of Interaction Design as a Cultural Practice*, Murray observes that unlike the previously established modes of media—such as books or newspapers—emerging media is still unstable in terms of its building blocks and design language. Advancements involve major innovation and invention as opposed to refinement.[1] For this reason, the idea of the "new" still persists, and in fact, dominates the discourse. But Murray cautions against overusing the term "new media" because it puts more emphasis on its (technological) novelty than its (cultural) significance. To assess the medium as a function of a considered language of design, Murray proposes shedding the term "new" and keeping only "digital media." Since design is at the core of this paper, I will adopt this distinction as well.

Do virtual environments constitute their own medium? In an editorial in the journal *Convergence*, digital media theorists Maria Engberg and Jay D. Bolter introduce the questions around the emerging language of digital design and discuss the cultural implications influencing the production of virtual environments.[2] They begin by explaining the origins of the virtual medium from the perspectives of art history, philosophy, and sociology. Perhaps most familiar to this paper's audience is the reference to the art critic Clement Greenberg's argument in the 1960s that every medium ought to develop its own unique characteristics. In this framework, Greenberg condenses his ideas into a call for "medium specificity." While artists and designers practicing within inter-media have since critiqued this inherently isolating view, its theoretical premise has remained influential. Engberg and Bolter, as an introduction to the issue entitled "Cultural Expression in in Augmented and Mixed Reality," draw parallels between Greenberg and the pioneering media theorist Marshall McLuhan, who broadened the definition of medium to include anything and everything that modulate our perception of time and space. In this paper, I argue that digital models as portals into virtual environments accomplish exactly that modulation of time and space but in such unique ways that they should be considered their own evolving medium.

However rapidly proliferating, the developments in digital media make up a continuum. Bolter identifies in several of his works the generative step from preceding forms to the newer version of a medium¬—he terms this transformation an act of "remediation." By his definition, remediation is the process in which a new form replaces the older one by adopting some of its features, modifying others, and ultimately reshaping its presence within the cultural context.[3] For example, Bolter discusses how writing on papyrus remediated the orally disseminated word, and how hypertext remediated text by mimicking the older form visually while serving as a departure point for other intertextual content. In "Spatialization: A Strategy for Reading Narrative," Susan Stanford Friedman describes textual narrative's relationship to spatial domains even more precisely. Narrative represents space in two axes—vertical and horizontal—where both allow movement through space and time in different ways.[4] The horizontality refers to the sequence of ideas in one context and the verticality implies a sense of going deeper into one idea and its associations with others in different contexts. Hypertext exists at the intersection of these two axes as an access point to both spatial and temporal navigation.

"REMEDIATION" OF ARCHITECTURAL REPRESENTATION: HYPERMODELS

With digital media now such an integral part of its production and representation, how can architecture be "remediated" toward more interactive forms? Sylvia Lavin, in "Architecture Animé or Medium Specificity in a Post-medium World," offers a historical and geographic account of architecture's search for its own possibility as a dynamic medium, since the 1960s and across the US, Italy, and Japan.[5] Soon after Greenberg's calls for medium specificity, the art and design world began to shed single-medium defined practices and to seek cross-disciplinary modes of expression. Influenced by the work of artists such as Andy Warhol, many architects' visions for the cross-medium and post-medium took the form of participatory and multisensory experiences, presented primarily as a critique of the immutability or the "frozen" nature of architecture. As an example, Lavin describes a project by an Italian architecture student who superimposed orthographic drawings on mylar onto neon lights to create spatial effects mimicking axonometric drawings. Lavin likens this "apparition" to how digital 3D models work today. Even though the results of these media boundary-exploring works predominantly created a disorienting environment of fragmentary and confusing space, Lavin contends that architecture, as a physical endeavor, will prevail, albeit while transforming into a "container" for digital media.

While Lavin's focus is on the relationship of the built work to digitized data, it is also about the representation of the physical artifact in digital space. The neon supported hologram drawings, which for her signaled precursors to 3D digital models, are an example of "legacy formats" holding on to obsolete aspects of an earlier technology at the expense of curtailing its remediation. I will argue that the power of the digital model is less to do with the transformation from 2D to 3D or even to building information modeling (BIM) platforms and more to do with how a "hyper" spatial domain emerges out of the representation of the architectural construct. This domain includes multimedia elements such as wikis, geospatial maps, and videos, and links to content from diverse disciplines, which are currently not typically supported by architectural representation technologies. It also shifts the perspective of the "user" to one of "interactor" (a term Murray strongly promotes), who engages with the digital space in real-time. Hence, I propose the term *hypermodel* as a remediation of the 3D digital platform and facilitator of a new, unique medium in two ways. One, it contains the information and interactive design language to represent the building changing over time. Two, it situates the architectural project in its sociocultural context through connections with heterogenous data. To use Stanford Friedman's analogy, hypermodels exist at the intersection of the horizontal (temporal) axis and the vertical (contextual) axis. It achieves both of these by facilitating an immersive environment, in which the interactor occupies both the new digital and the physical spatial domain.

More than simply a self-contained digital 3D model, the hypermodel gives access to a "hyper" environment endowed with a suite of possible applications. Current modes of this environment include what are commonly termed Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR produces a digital representation of a space where the interactor might navigate freely, and engage with other participants and the design interface to extract more information or adapt the settings. VR is an entirely immersive experience, where the interactor is willingly "fooled" into believing that they are present at a place other than the one they physically occupy. While in VR the digital space of the HyperModel is dominant and seemingly all-encompassing, AR relies on layering. The digital is layered on top of the physical to create access points into the virtual world through specific trajectories that enhance the experience of the physical world. In AR, the hypermodel is in the background, serving the interactor immediately and in seemingly invisible ways. Lastly, MR operates on a robust reciprocity between the digital representational space and the physical one, where objects in either space can interact with each other in real-time. If hypermodels generate a spectrum of relationships between the digital and physical, thereby a range of experiences for the interactor, MR occupies the middle where there is complete overlap and possible negation of the distinction between the real and the virtual. The spaces are entirely fluid, extending into each other's domain and mixing with one another.

I have proposed that the hypermodel is the remediated form of 3D digital models. Next, I want to look more specifically at how the new medium facilitates architectural representation and what kind of messages it generates. To do that, I want to briefly consider the idea of "virtuality" and reference the philosopher Elisabeth Grosz via her collection of essays entitled *Architecture from the Outside*.[6] Grosz contemplates virtuality and its history as part of the cognitive process. The human mind entered virtual space as early as the wall paintings of the caves in Lascaux, France, and mastered the craft of virtual worlds through the perspectival construction of Renaissance paintings. In another sense, narrative fiction pulls one into a virtual space. However immersive it is, Grosz argues, the virtual world is not an alternative but an extension of the real world. Virtual adds, shifts, enhances, but cannot replace. In that sense, Grosz asserts the separation of virtual from simulation.

This distinction is powerful for architectural representation because it frees the 3D representation project from one that is bound by the pursuit of photorealism—singular likeness—and allows for the pursuit of expression and synthesis—generative multiplicity. Hypermodels are able to incorporate varied content beyond and underlying the building as a physical artifact. Interdisciplinary scholarship and research find a spatial container in the hypermodel and reveal the intangible factors pertinent to an architectural project. Due to their interdisciplinary and inter-media nature, hypermodels are projects of ongoing collaboration. As a tool, the hypermodel generates a new medium of design, delivery, and operation, and, in turn, the medium alters the culture of work within the industry. The following examples show how the hyper virtual environments, enabled by various technologies, serve the architectural project as a collaborative endeavor.

COLLABORATION THROUGH HYPERMODELS

As an alternative to studying collaboration between specific stakeholders in the design process—whether from the industry or academia—I propose to trace the outcomes of the medium itself. In other words, my selection of the following projects was based on the fact that they implemented hypermodels, rather than on the roles of those involved. Through a closer look at the interdependency between the digital and physical spaces involved in each project, I argue that new medium of the hypermodel both requires and alters collaboration.

The first example aims to better integrate the domains of the "designer" and "builder." The "designer" typically includes architects and consulting engineers and other kinds of designers; builders include the construction manager or the general contractor and subcontractors, and the project management team. As part of the 2016 AEC Hackathon in Helsinki, Finland, one of the hosts, SWECO, a Finnish construction and engineering company challenged the participating teams to find technological solutions to making the shared work between project stakeholders more collaborative.[7] "Team Safety," whose members included technologists from TrimbleConnect, the cloud-based collaboration platform designed to integrate with BIM and other software, decided to propose a solution to improve communication between the field and the office, with the goal of increasing job safety.

The proposed scenario is a remediation of the BIM model, in that it implements AR technology to bridge digital and physical space at full scale. This bridge is bidirectional, placing the designers on the job site through digital space and allowing the builder access to the digital representation of the project in real time. The digital model becomes a dynamic reference during the construction process. This example works to improve existing models of collaboration between industry partners by facilitating a shared, dynamic platform and real-time data input. As a result, the data lost in translation is minimized

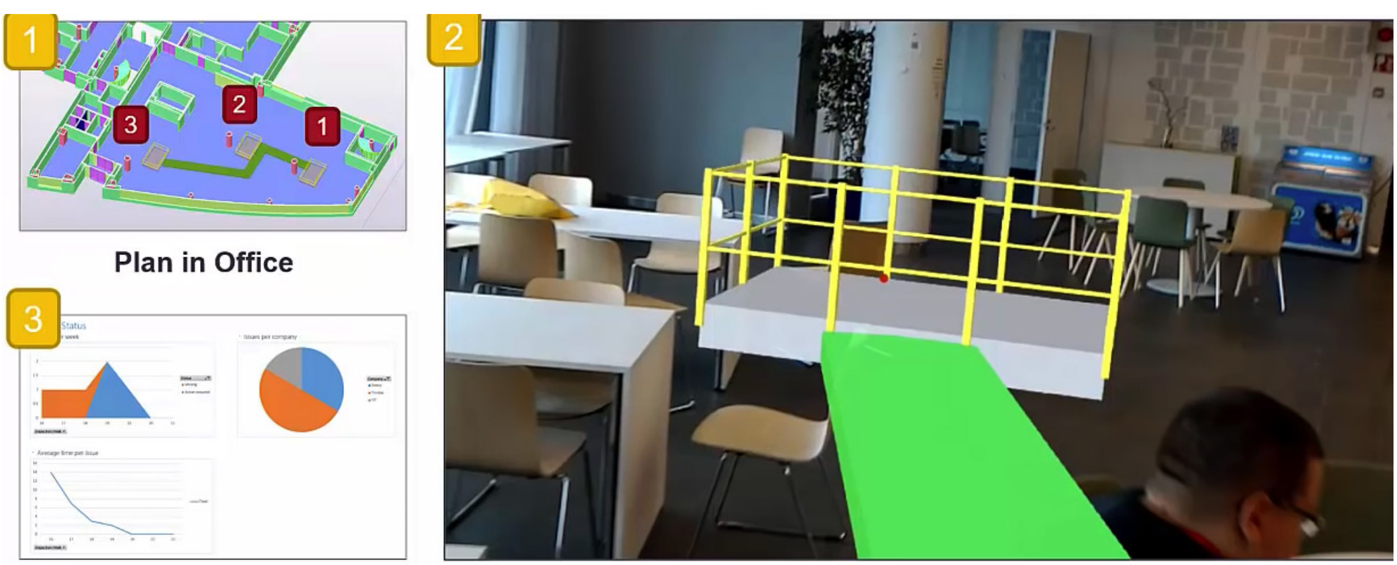

Figure 1: Screen capture of "Team Safety" presentation

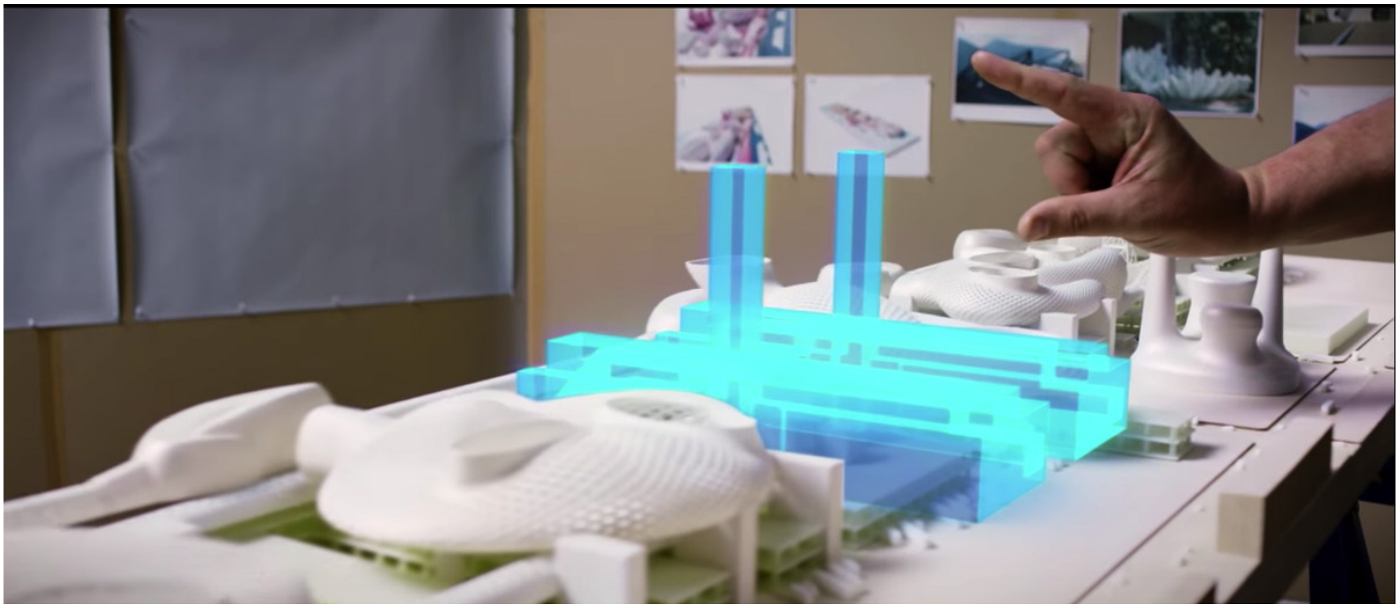

Figure 2: Screen capture of Lynn and HoloLens partnership video

and information "lives" not only within the digital model but also in the extension of the digital model located in the physical space. Annotation is contextualized and obsolescence eliminated.

While job site safety is the "test case" for this project, the technology can be applied to other critical aspects of construction, an effort that requires dynamic and synchronized communication between the various parties involved. Its facility to enhance communication can also aid post-construction activities related to the operation of the building, such as commissioning, post-occupancy data analysis and maintenance. In this sense, processes of design, building, and operation can use the same hypermodel, which remains current throughout the life cycle of the building and serves short and long-term problems demanding spatial coordination among team members with different areas of expertise. The "bridge" between the office and field can be multi directional and engage with other routes of communication.

The second hypermodel project is a collaboration between the architecture office Greg Lynn FORM, and Microsoft in partnership with Trimble in the development of the wearable AR device *HoloLens*.[8] The context for the project is the 2016 Venice Architecture Biennale. The organizers invited Lynn to work on a re-use design project of the Packard Plant in Detroit, the abandoned site of a former automobile factory. In a video promoting the partnership and Lynn's initial use of the AR headset, the architect describes the details of the project brief and the early phases of design. Standing next to a physical site model of the super-block and wearing the headset, Lynn enters into the digital space of the hypermodel (the video switches to his point of view). To better grasp the scale of the Packard Plant site, he accesses the digital library provided through TrimbleConnect and "grabs" with his hand a model of the Tate Modern in London. An iconic building well-known to him and other designers, the Tate serves as a volumetric reference. By replicating the digital massing model layered on the physical site model, Lynn concludes that his project is equal to twelve Tate Moderns.

In this mode, the architect is collaborating in a general sense through the digital libraries with the creators of the data stored there. The digital library becomes the agent of collaboration while the act of working together happens primarily extemporaneously. The shared activity proliferates to other times and places, where the designer has a team of distant partners contributing to the work in various ways. Architects' primary role in collaborative work is most often the task of synthesis. This process of absorbing, processing, and editing heterogeneous data is better supported through AR technology because it enables not only faster but more educated decision-making. In terms of the affordances of hypermodels, the designer can go deeper into the "vertical" space of the model—the cultural and sociocultural data—to access the history of the neighborhood, for example, and inform decisions regarding say program and use. The hypermodel negates the illusion of the architect creating in isolation and reinforces the networked nature of digital space, containing the input of a diverse set of contributors, where all critical decisions are made.

The video of Lynn utilizing the AR headset demonstrates a physical representation—in this case a massing model—functioning as an anchor onto which electronic media can be tethered. The Trimble library, as the container of a networked and scaleless database, exists in the digital realm but finds context within the physical representation to a particular scale. It exemplifies augmented reality, in which digital layers reveal or enhance an aspect of the physical "base." Lynn uses the hypermodel to cross-reference scalar or formal information, however, one can speculate that the comparison does not need to be only in terms of volume but can draw corollaries between commercial, historical, social, and logistical databanks. Given the history of the site, the references informing the design could conceivably come from a multitude of sources related to the heritage of the automotive industry in the city.

The last project example involves new media technologies as implemented in the digitization of cultural heritage sites. Initiated in 2015, it marked a collaboration between the UNESCO Chair in “Management and Promotion of World Heritage Sites: New Media and Community Involvement,” at Kadir Has University, Istanbul, Turkey, and the leading Turkish BIM software distributor, Bilkom. The team consisted of myself, other faculty members Assoc.Prof. Yonca Kosebay Erkan and Prof. Füsun Alioglu; undergraduate students from the Architecture department at Kadir Has, and technical experts on ARCHICAD, the building information modeling software represented by Bilkom in Turkey. Therefore, one educational goal of the project was for the students to learn and practice the collaborative use of this specific platform.

The team selected the Studius Monastery Church, later known as the Mosque of Imrahor, as an appropriate initial case study for a digital reconstruction project. Built near the Golden Gates of Constantinople in the 5th century, the Studius Monastery was not only a religious destination but also a center of cultural and intellectual life in Byzantine Empire. The oldest surviving religious building in the city, the site has been abandoned for decades, but is slated for a controversial and imminent renovation to convert it back to an operational mosque. Over the course of 16 centuries, due to changes in ownership and use, numerous powerful earthquakes and fires, and other beautification projects, the church went through a series of architectural modifications—in the form of fills, extractions, and overlays—at varying scales and scope, resulting in a build-up of material layers, albeit with little legibility in terms of their provenance. The resulting current physical artifact is an amalgamation of its layers of reconstruction, making its translation to BIM extremely challenging.

Along with digital modeling, the team also engaged in close analysis of existing documentation of the building researched the historical “layers” of the architectural and geographic site. The technological challenges necessitated a phased approach to modeling, in which the initial installment of the project focused on a single aspect of the site’s history. The team decided to transfer the Byzantine basilica in its 11th century condition, at the peak of its social prominence and architectural presence, to the digital environment of ARCHICAD. This decision entailed the task of deciphering and uncovering later modifications. The relatively narrow focus was motivated by the academic calendar of the university as well as the steep learning curve the software initially demanded.

The technical challenges of collaborating upon the digital reconstruction of a historic building created a critical limitation, reducing the physical, temporal, and inevitably, conceptual scope of the project. The major challenge with ARCHICAD was the question of how to represent or recreate the Roman masonry structure along with the intricate finish work within the interior, all while implementing a tool specifically tailored to contemporary standards and components of construction. Therefore, a “well-built and clean” model and a “finished” visualization of the basilica would essentially erase the sense of time—and represent

Figure 3: View of the current state of the apse. (Photograph by Esra Kudde)

Figure 4: Exterior wall detail (Photograph by the author)

a singular, arguably less accurate, rendition of history. Furthermore, a robust BIM platform would necessarily encapsulate the project within a specific temporal identity and a particular set of industry standards. Instead of a purely logistical BIM model, the representation of such a site would require essentially a "sociocultural BIM" model.

How could the implementation of a hypermodel improve future phases of this project? The speculative answer revisits Stanford Friedman's analogy of horizontal and vertical axes in digital space, and shows how it becomes critical in conceptually organizing information on the site. The hypermodel allows the interactor to navigate "horizontally" within the representational space—between multiple instances along the timeline of the building—thereby achieving a synthetic understanding of its continuous material transformation through the course of centuries. One can stand in the 5th century basilica and juxtapose it against the architectural modifications carried out during its conversion to a mosque. The immersive experience powered by hypermodels in MR mode removes the conceptual "edge" around the digital model such that the interactor is present within the digital space, where layers of intangible "drivers" behind each instance of reconstruction are revealed. For instance, the change in Islamic liturgical practice that required more private interior spaces show up in the digital model as a series of masonry fills completed in the 17th century. The hypermodel also allows the interactor to navigate "vertically" between multiple object scales, honing in on the full extent of its construction and its basis in traditions of fabrication, networks of material sourcing, and historically expressive motifs. Akin to the familiar action of visually "zooming in and out" in digital space, the interactor occupying the hypermodel "zooms in" to investigate the details of the chemical composition of assembly components and "zooms out" to see building scale finish patterns. Furthermore, MR mode opens the model up to other data libraries such that, when standing at the apse of the Church of Studius and studying the stone paneling on the interior walls, one can "pull up" the visual documentation on other Byzantine monuments and compare their designs or access literature on Eastern Roman visual culture to analyze details of stone carvings. While the hypermodel's full capabilities are still speculative, my ongoing research deals with the integration of the archival data on the building within a dynamic 3D model presented in an interactive, web-based and virtual reality environment.

CONCLUSION

Architects must consider digital models in the context of media and new capabilities not simply as a robust platform for storing and sharing information regarding the physical elements of a building, but as a dynamic and interactive domain of communication and medium of representation that reveals the intangible aspects of architectural production. These so-called hypermodels, akin to the functionality of hypertexts, both contain and connect to outside sources of information. Embedded within them are multiple scales of architectural information as they change along the temporal axis. As a connector to other types of information, the hypermodel provides access to a variety of digital libraries, which in turn updates the model with heterogeneous and dynamic data. The hypermodel is intrinsically an interdisciplinary endeavor. However, it goes beyond bidirectional sharing of information and spatializes the exchange of information. More so, the hypermodel contextualizes the larger project relative to its social, cultural, and political contingencies. This renewed perspective reinforces the medium of collaboration within the professional and academic field while also expanding it past the common disciplinary delineations. The collaborative architectural endeavor promises more than the efficient multiplication of team players: as architects, we must envision the critical proliferation of access to an expansive breadth and immersive depth of knowledge.

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People-Space Analytics: Case Study of Work Dynamics

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To deliver an innovative design, architects often need to innovate in the ways they empathize with and understand the user. In his 1994 essay, the American Pragmatist philosopher Richard Rorty writes that "one should stop worrying about whether what one believes is well-grounded and start worrying about whether one has been imaginative enough to think up interesting alternatives to one's present beliefs"[1]. This study, primarily, explores an interdisciplinary approach in which data collection, analysis, and interpretation are used as drivers of inspiration as well as tools of validation. A combination of tools and techniques labeled as people-space analytics was used to investigate the socio-spatial dynamics of work in the workplace of a national architecture firm. The results were later interpreted from a certain lens in the community of practice theory. A secondary goal of this research project is to study how workplace's spatial configuration and key people and places are involved in organizational learning and knowledge practices. Therefore, a set of metrics and measures were used to interpret different employees' recurrent patterns of communication and flow of information between people from different social networks in a spatial context.

INTRODUCTION

Workplace is a complex ecology comprised of various correlational relationships between people, spaces, objects and artifacts, practices, technology, and information. These correlational relationships are important because they are often directly tied to important workplace outcomes such as recruitment and retention, business performance and productivity, efficient allocation of resources and spaces, brand and culture, return on real estate investment, work-life balance, and strategizing for knowledge practices among others. That said, decoding this ecology in its entirety is neither easy nor necessary. A useful investigation could reveal meaningful constellations within this ecology (Figure 1). A typical workplace constellation might include a certain team's work-dynamics and its generational make-up,

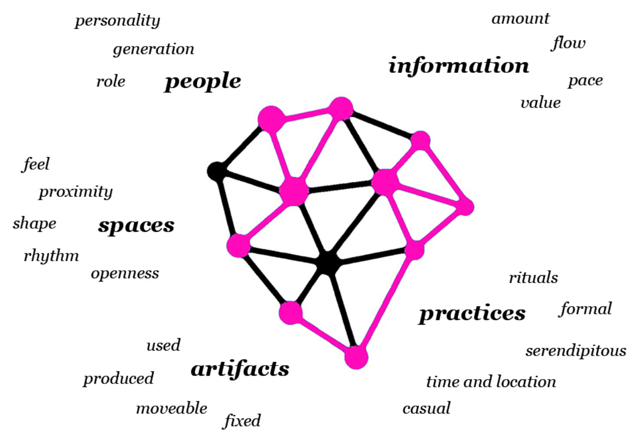

Figure 1: Meaningful constellations within the workplace ecology

configuration of spaces they use, and the variety of moveable furniture within those spaces. But almost similar to the tales of zodiac in the sky, a meaningful constellation in the workplace should tell us a compelling story. Yet before getting into the details of this study's narrative, we will first explore the theoretical lens, techniques, and measures used to gather and make sense of the data.

COMMUNITY OF PRACTICE (CoP) THEORY

The community of practice perspective is largely conceptualized and explained by the social learning theorist Étienne Wenger[2,3,4,5,6,7]. Wenger explains that his theory has its roots in the attempt to develop accounts of the social nature of human learning inspired by anthropology and social theory reflected in Lave's conceptualization of cognition in practice[8], Bourdieu's habitus/field theory[9], Giddens' structuration theory[10], Foucaultian concept of power[11], and Vygostsky's zone of proximal development[12]. CoP has also been widely referred to as a key component of a knowledge strategy in organizations[3,13,14,15,16].

Since the early 1990s, the concept of CoP has been extensively used as a theoretical construct, a practical learning and knowledge strategy, and an effective managerial tool to address issues of individual learning and organizational development across multiple social science disciplines and professional fields[17,18,19]. Therefore, there have been various interpretations of the concept. In their brief introduction to CoPs, Wenger and Trayner[20] define the concept and address some of the assertions about it:

> *"Communities of practice are formed by people who engage in a process of collective learning in a shared domain of human endeavor … [they] are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly … the role of CoPs is [not only] to share knowledge … [but also] to innovate and solve problems."*

In workplaces, a CoP grants different levels of participation to learners and legitimizes persons' positions on the periphery of practice. In other words, it enculturates learners[21] and encourages them to become insiders by learning to function in the community[13] and becoming more competent members.

PERIPHERY, BOUNDARY, AND BOUNDARY MECHANISMS

Wenger tends to use geographical metaphors in explaining his theory, possibly more than any other theorist of social learning and knowing. However, one needs to be mindful of the fact that his application of these terms is not literal and the direct extension and generalization of them to the material realm will most probably lead to misunderstanding. Consequently, examining Wenger's theory in the context of an architectural academic effort requires additional sensitivity towards the theory's terminology. Thus in this and next sections, differences and similarities between several important terms in the context of CoP perspective are explained. These terms include periphery, peripheral participation, boundary, boundary object, and brokering.

According to the CoP theory, as novices initially join communities of practice, they start learning at the periphery. This mode of learning happens as newcomers participate in low intensity and low-risk yet productive and necessary activities. For their learning experience to be authentic, peripheral participants are also granted legitimate access to resources of the community including its members and shared repertoire in use. Therefore, as the newcomer becomes acculturated to the norms and practices of the community, she becomes more knowledgeable, develops mastery identity, and eventually turns into an old-timer. Of course, peripheral members take responsibility of certain tasks that are necessary for the functioning of the community. However, as they move from peripheral to more active and core participation in the community, become more central, and construct new identities, they also naturally engage in a process of negotiating the identity of the community of practice. The constant negotiation of meaning contributes to the community's longevity, evolution, or paradigm shift as long as it keeps recruiting new members, and, of course, its core practices are not disrupted by other communities in the landscape.

While peripheral participation has an inward tendency and is concerned about its host community of practice, boundary turns the focus outward and encourages the community to consider the broader landscape of practice. Wenger[7] explains that boundaries are the inevitable consequence of learning as the production of practice. They are not, necessarily, created because of participants' intentional desire to exclude outsiders. It, in fact, is the shared history of learning amongst members and their situated knowledge about the domain that distinguishes them from those who are not involved in the CoP:

> *"Practices are like minicultures, and even common words and objects are not guaranteed to have continuity of meaning across a boundary. At the same time, boundaries can be as much a source of learning as the core of a practice. The meetings of perspectives can be rich in new insights and radical innovations. Still such new insights are not guaranteed, and the likelihood of irrelevance makes engagement at the boundaries a potential waste of time and effort. Indeed, competence in not well defined at boundaries. This means that the innovation potential is greater, but so is the risk of wasting time or getting lost."*

Various boundary mechanisms can be the source of continuities and discontinuities across different communities of practice. Two types of boundary mechanisms that encourage connection between communities are boundary objects and brokering. Boundary objects are artifacts, documents, terms, concepts, and often forms of reification around which communities of practice can organize their interconnections whereas brokering includes connections provided by people who can introduce elements of one practice into another[4]. This role creates connections between people from different organizations, cultures, sectors or localities, brokering and translating varying perspectives, and facilitating the application of ways seeing and doing across different domains[22]. Wenger[4] writes that most of us in occasions exhibit brokering behavior. Yet, there seem to be individuals who thrive on being brokers:

> *"They love to create connections and engage in 'import-export,' and so would rather stay at the boundaries of many practices than move to the core of any one practice. The job of brokering is complex. It involves processes of translation, coordination, and alignment between perspectives … Brokering often entails ambivalent relations of multimembership."*

In this study we focused on brokering as a type of boundary mechanism or activity whose conveyor, as opposed to a boundary object, is the individual person.

METHOD

According to several researchers including Wenger himself, there is validity in using social network analysis (SNA) methods and techniques in understanding CoPs. In 'communities of practice and social learning systems' Wenger[7] writes that the concept of community emphasizes identity while network focuses on connectivity. Yet he also argues that the two usually coexist and CoPs are certainly networks in the sense that they involve connections among members. There are examples of studies such as Marsico et al.[23] and Cross et al.[24] which use SNA methods and metrics to map CoPs.

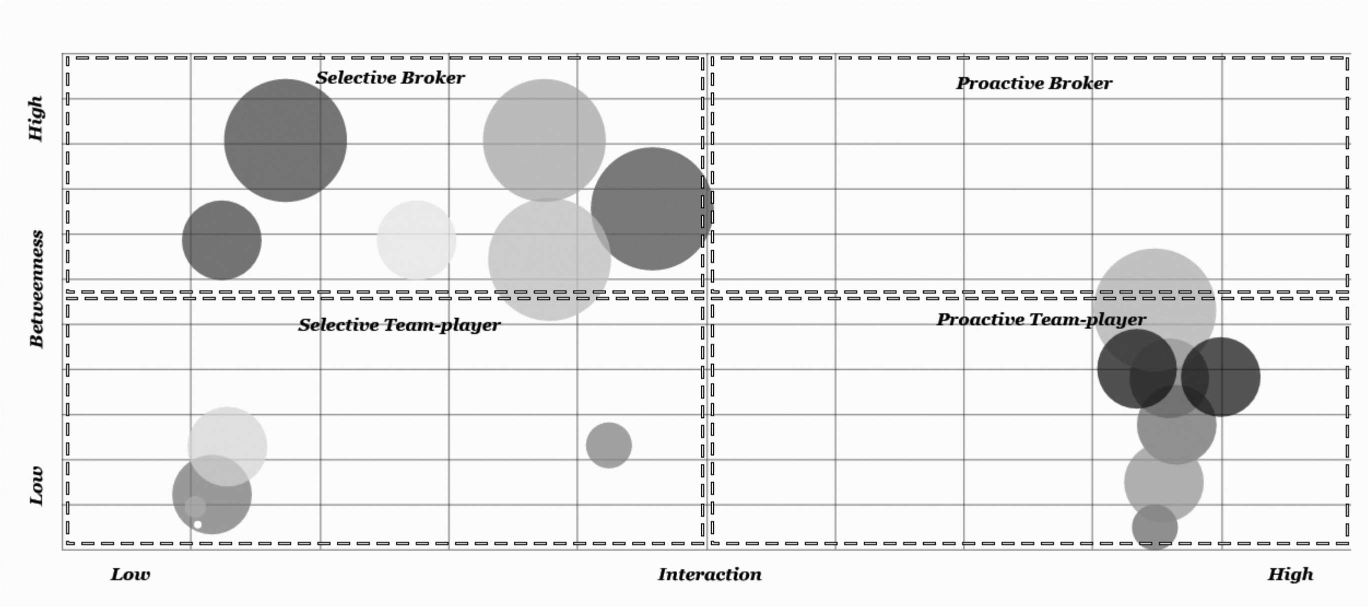

Figure 2: Boundary activity = f (betweenness, weight, degree)
Each bubble represents a person and the size represents the node's degree.

People-space analytics is a term that we use in this study to describe an approach towards capturing and analyzing social dynamics in the physical space for providing data-driven accounts about how organizations use the physical space. People-space analytics toolbox employs different technologies, techniques, and theories – from tracking social interaction and location to incorporating SNA and CoP perspective into physical space occupancy data.

People-space analytics uses various knowledge and learning theories to make sense of the collected information, yet on the methodological level it draws inspirations from the work of Human Dynamics Lab at MIT Media Laboratories. This methodology is captured in Alex Sandy Pentland's[25] definition of social physics:

> *"Social physics is a quantitative social science that describes reliable, mathematical connections between information and idea flow on the one hand and people's behavior on the other. Social physics helps us understand how ideas flow from person to person through the mechanism of social learning and how this flow of ideas ends up shaping the norms, productivity, and creative output of our companies, cities, and societies."*

Ben Waber, a visiting scientist at the MIT Media Lab and the author of 'people analytics: how social sensing technology will transform business and what it tells us about the future of work', is also a proponent of data-driven strategies for building better organizations. Although Waber's work is mostly focused on the social side of organizations, he has acknowledged the significance of physical and spatial qualities of workplaces in several occasions[26,27]:

> *"Companies should always look to physical space as a key part of their toolbox for changing patterns of collaboration and behavior. The actual layout of the office, the type of furniture, and the decision to let employees work remotely all have a profound impact on both companies' and individuals' success. Distance is not dead. If anything, it's more central to our lives than ever."*

Work-persona questionnaire was one of the surveys launched in this study. The multiple choice questionnaire asked participants to choose three personas that they sympathize with out of 10 personas described in 'the ten faces of innovation' by IDEO's Tom Kelley and Jonathan Littman[28]. Observation and note-taking were also implemented.

FINDINGS

To provide structure for a more detailed exploration of boundary mechanisms in the workplace ecology, we framed our work around three fundamental research questions pertaining to these mechanisms in the physical space: (1) How can we describe boundary mechanisms as SNA-related constructs in space? (2) How can we map them relative to space? (3) How can we evaluate them relative to space? Certain measures and metrics in SNA help us answer the first question. For example, betweenness centrality, as a measure for quantifying the control of a human on the communication between two other humans in a social network[29], is indicative of brokering or peripheral behavior. As a matter of fact, Pentland[30] also uses this measure to explain how often people go exploring outside their team and bring new ideas and information back.

So a boundary activity is a function of betweenness centrality, but is it not also a function of amount and number of interactions? Waber et al.[31,32] and Wu et al.[33] explain that there is a strong correlation between interaction and performance, but their definition of performance does not take betweenness centrality into account. That said, a significant number of workplace designers, especially proponents of drawing inspirations from urban life to create better work spaces – Frank Duffy, Clive Wilkinson, Herman Hertzberger, among many others – , seem to indicate that strategies which help increase interactions will eventually result in more chance encounters. For example, Duffy[34] believes what

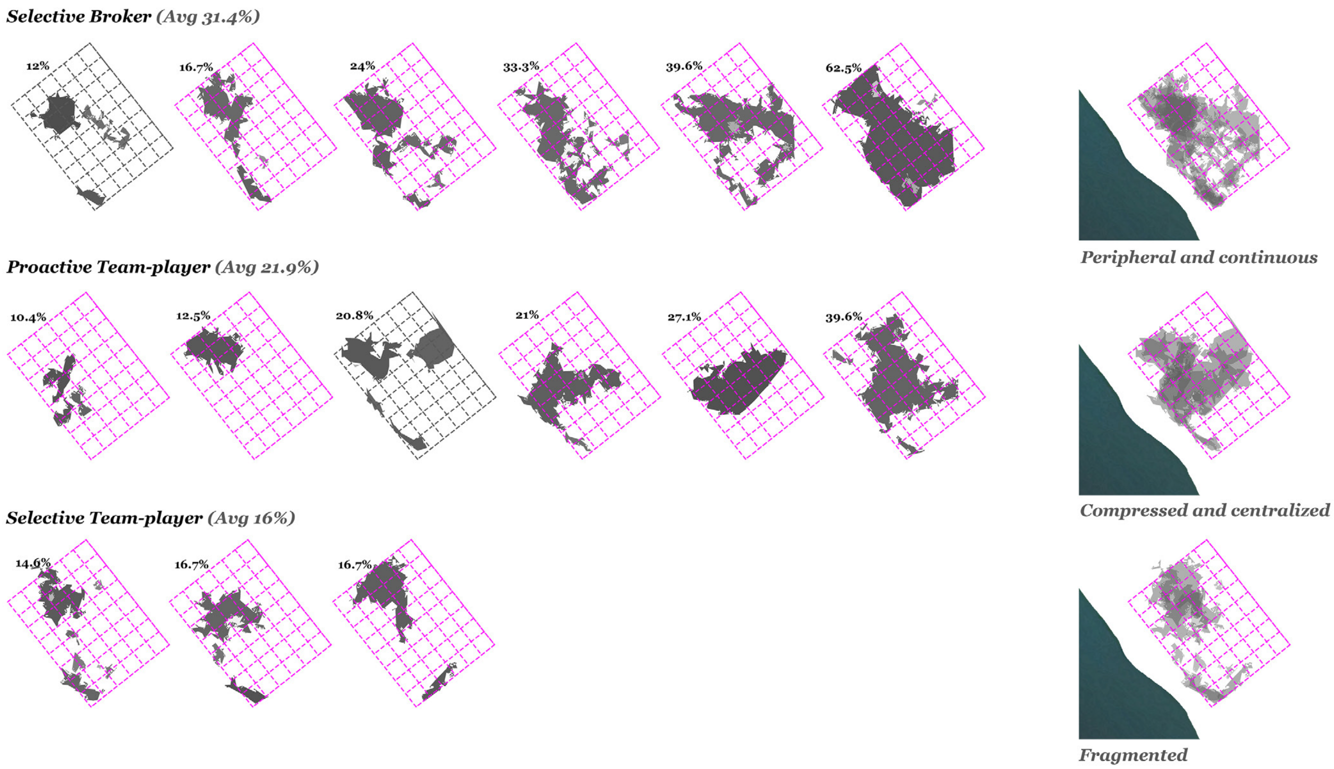

Figure 3: Space-use patterns accorss selective brokers and team-players

constitutes for the success, productivity, and congeniality of the city social life is the density of overlap among various social networks.

Similarly, several of our study participants thought that there is a logical connection between the two. For example, one study participant said: "More interaction is definitely good. You'll eventually talk to people with higher probability of relevance." Another participant believed: "You want for more people to talk to each other. That's how new ideas are born." In other words, more exposure through interaction will increase the chance for activating boundary mechanisms. Considering all this, the definition of boundary activity in our study takes betweenness centrality, the amount of interactions, and the number of people with whom interaction has happened into account: Boundary activity = f (betweenness, weight, degree). This provides a basis for answering the second and third questions regarding mapping and evaluating boundary mechanisms in the physical space.

Using the data from sociometric badges, Figure 2 shows different individuals' level of engagement in brokering. Selective team-players in the bottom left quadrant are those with the lowest amount of interaction and exploration. They mainly remain inside their social network and tend to be more strategic about their inward interactions. Similar to selective team-players, proactive team players in the bottom right quadrant also conduct most of their interactions with regulars in their immediate social network, yet they seek more interactions with their fellow network members. Both selective brokers and proactive brokers in the top two quadrants tend to explore and interact with those outside their network. As opposed to selective brokers, however, proactive brokers are dedicated to connecting different disciplines and networks to one another. None of the participants in the study fell into the proactive broker category, and the majority of selective brokers had a higher degree. Interestingly, according to the matrix, proactive team-players with higher degree – larger bubbles in the bottom right quadrant – have a great potential to become proactive brokers and the majority of selective brokers have also a high degree. This confirms the workplace designers' urban life theory about the correlation between serendipitous encounters and the number and amount of interactions with different people.

Are there similarities and difference in how these three groups use the physical space? The data from location monitoring exhibited in Figure 3 revealed that, in average, selective brokers use more space than proactive team players, and proactive team players' space utilization is higher than selective team-players. Moreover, the first group's space utilization pattern is more continuous, whereas the majority of team-players move between one or two spots. This means explorers, with higher betweenness centrality, not only tend to travel more often and tend to use more resources in the workplace, but also, compared to team-players, they anchor in more spaces. They do not just run into people and conduct short conversations; they pause and establish meaningful ties.

Location plots also imply that the majority of brokers prefer to 'go to people' in different locations rather than host them. This is an important trait especially when it comes to learning through peripheral participation. However, interestingly, the majority of brokers were at

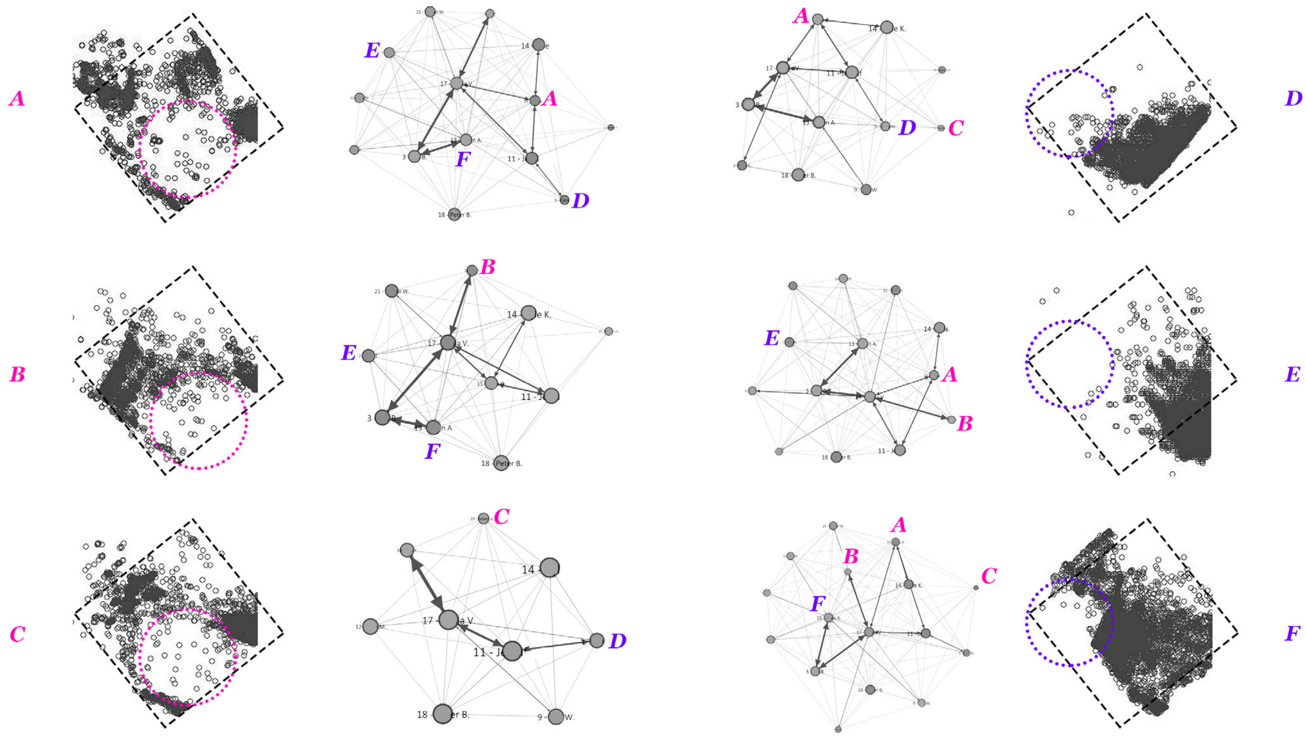

Figure 4: Individuals with complementing location plots and their social networks

the higher levels of organizational hierarchy. Another important finding was revealed when we studied a sample of participants' patterns of territorial behavior in relation to their social networks. Figure 4 shows that people whose location plots complement each other have the lowest level of interaction with one another. For example, the void in the location plots of persons A, B, and C can be filled with the location plots of persons D, E, and F, and consequently, the individuals from the two groups rarely interact. This could be a potential problem if boundary mechanisms between the two groups could possibly result in useful and positive outcomes for the organization such as better collaboration, more innovation, better flow of information, or more effective mentoring. Recognizing the situated, transactional, and correlational relationships between the social and the spatial, the national architecture firm has decided to redesign the void along with other spaces in the workplace and launch a second research study to learn if there will be any changes in existing brokering patterns.

DISCUSSION AND FUTURE DIRECTIONS

In architectural practice, it is customary for most data gathering tools and methods to be considered as part of the Post-Occupancy Evaluation (POE) arsenal. Social and spatial analytics tools and methods are not exceptions as they help architectural programmers and designers gain insights which often cannot be captured using conventional survey methods. That said, people-space analytics, at its core, is an empathy-building tool because it encourages end-users to participate in a conversation about the kind of socio-spatial patterns which support and promote organizational goals. Moreover, it provides the possibility for the organization to experiment with the use of space while mapping the impact of different spatial scenarios on important outcomes.

Finally, people-space analytics, as a combination of tools, techniques, and theories, can provide a useful framework for (1) defining, (2) mapping, and (3) understanding how social and spatial patterns relate to important outcomes in a workplace setting. A potential fourth step would be intervening in or improving those patterns being mindful of the fact that intervention in patterns goes beyond designing the physicality of the workplace and requires engaging participants in the process of changing the ways work is being conducted.

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Prototyping in Glass: Two-years of Collaboration with the Corning Museum of Glass

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This paper documents two years of collaboration with the Corning Museum of Glass (CMoG), where two groups of graduate architecture students lead by a team of two faculty members, were able to develop projects – architectural glass components – in consultation with glassblowing experts and the resident material scientist at CMoG, and ultimately participate in the fabrication of the prototypes at CMoG's world class glassblowing facility, GlassLab.

INTRODUCTION

This paper documents experimentations with glass to prototype architectural components as an offshoot of a research project that began in 2009 into the development of a glass block facade component filled with PCM (phase change material). While the first phase of the research, done in collaboration with the chemical company BASF, focused on empirical testing of wax PCM, the current phase focuses on glass itself, and reveals how challenging it is to work with the material in an experimental way. Working first-hand, in an experimental manner, with glass presents several challenges. Unlike materials like concrete, plaster, and even ceramics, glass can only be formed with exposure to extremely high temperatures, and requires special facilities, tools and specialized skills. This paper documents the outcome of an architectural design studio dedicated to glass in architecture, taught for two years; first-hand experimentation with glass resulted in prototypes at the architectural component scale. Research was conducted with the cooperation of the Corning Museum of Glass (Cog) and their state-of-the-art Glass Lab facilities for hot glass work. Simultaneously, work with kiln-formed glass was conducted at the university, using refractory molds and both ceramic and glass kilns.

The results of the student experiments revealed the limitations of one-off artisanal glass production techniques – both warm and hot – in making prototypes that require extremely high degrees of precision.

With the Thermometric Façade we investigated the intriguing material properties of wax phase change material and developed an architectural proposal from the material specificity of wax phase change materials. Glass turned out to be an intriguing phase change material in its own right and allowed us to speculate on its' architectural potential in a material specific manner. In the following I will describe three student projects selected from twelve projects that emerged over the course of two design studios.

GRADUATE DESIGN STUDIO PROJECTS:

VARIATION INSTEAD OF REPETITION IN KILN FORMED GLASS (STUDENT TEAM: KIM SASS, STEVE SMIGIELSKI)

The first project began by tackling the challenge of creating forms that are typologically related but geometrically different. In kiln formed glass casting, molds typically produce identical forms and formal differences or aberrations between the cast pieces are seen as undesirable. The same holds true for the fabrication of aggregated building elements. Bricks, for example, should have the same dimensions to be laid as a brick wall in an efficient manner.

This project, however, looked how glass casting could lead to a family of forms which are clearly identifiable as belonging to a single formal typology, with individual, geometric variations within that typology. Trees and icicles served as precedents for this project. Although each tree is geometrically distinct, we can clearly read them all formally as trees. All trees also follow the same structural principle, although they are geometrically distinct. Icicles are also all formally different, although we identify them in a generalized category as icicles. Icicles also share some distinct qualities with glass: they are inanimate, they are translucent and they are brittle. Combined with the cold weather in the spring term in Buffalo, NY, ice was an affordable and accessible substitute material for the students to use to investigate the research question further. Similar to the process of ice formation, the project utilizes material-specific processes to yield variety and differentiation, in this case by looking at the age-old technique of kiln-formed glass in a mold. Instead of designing a precise form, this project develops a glass-specific fabrication process that generates forms that are geometrically different but typologically identical. In a second step, students investigated how these non-identical elements could be clustered through an aggregation logic that allows for high tolerance similar to Velcro surfaces that stick together without the need for precise placement. First tests with ice sintering produced agglomerations of icicles that were branchy and triggered thinking

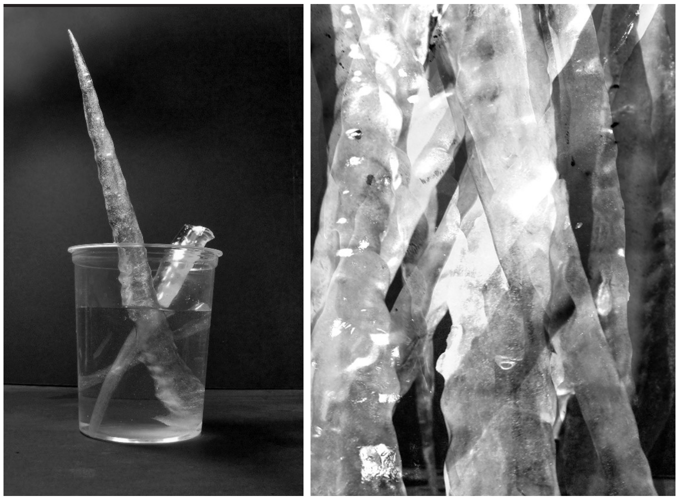

Figure 1: Sintering of Icicles (Image: Steve Smigielski)

about modules that could start interlocking in a similar manner to the anti-tank barrier known as Czech Hedgehog.

Sintering is the process of creating a singular solid from several parts through heat or pressure without reaching the melting point of the material (Hobbs and Mason [1]). The students learned to produce branchy modules that where all geometrically different while at the same time belonging to the same family of forms. The modules also demonstrated the ability to interlock in unexpected and seemingly random ways. The idea of aggregating non-identical modules into larger, stable assemblies was then tested with branch knots. Tests demonstrated that as the respective branches pointed in opposite directions, the aggregated mount became higher.

In a next test, students investigated the potential of scaling. Similar to the investigations by Eiichi Matusda under the direction of Michael Hensel and Achim Menges, the students dropped modules on top of each other as an aggregation method (Matusda et al. [2]). But in contrast to Matusda different scaled modules were poured on top of

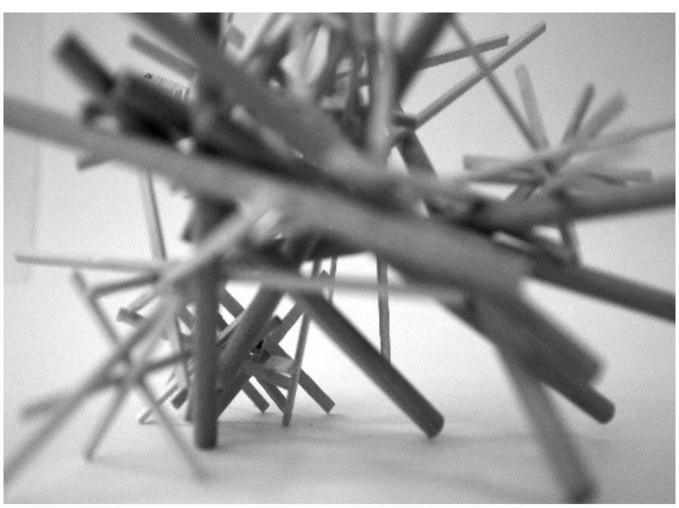

Figure 2: Scaling of identical modules creates spatial pockets. (Image: Steve Smigielski)

each other. This test produced interesting spatial pockets, without the need for formwork to create enclosed space. Scaling addressed not only the structural aggregation of modules but also the creation of space. The knowledge gained from these preliminary tests was then combined and introduced into glass-making process which involved:

• devising a fabrication process that creates a family of related forms instead of a fixed form;

• using an assistive mold similar to the icicle cup instead of a mold that fully enforces its shape onto the cast;

• using a hierarchy of radically different scales to create larger aggregations and inherent spatial pockets;

The students used glass rods and started with simple bisque cups for the assistive mold. Because the mold had a circular section, it was difficult to place it into the kiln without moving the glass rods into an all-parallel bundle. As the glass rods tended to cluster in an all-parallel bundle in the round cup mold, different mold geometries were then tested. The students proposed a hexagonal mold into which the glass rods were tossed. This mold geometry produced a wider variety of fused glass clusters and could be moved without changing the arrangement.

As the glass tacking temperature is higher than the slumping temperature, the sintering outcomes were very different from the earlier ice studies, producing droopy forms with bent branches that

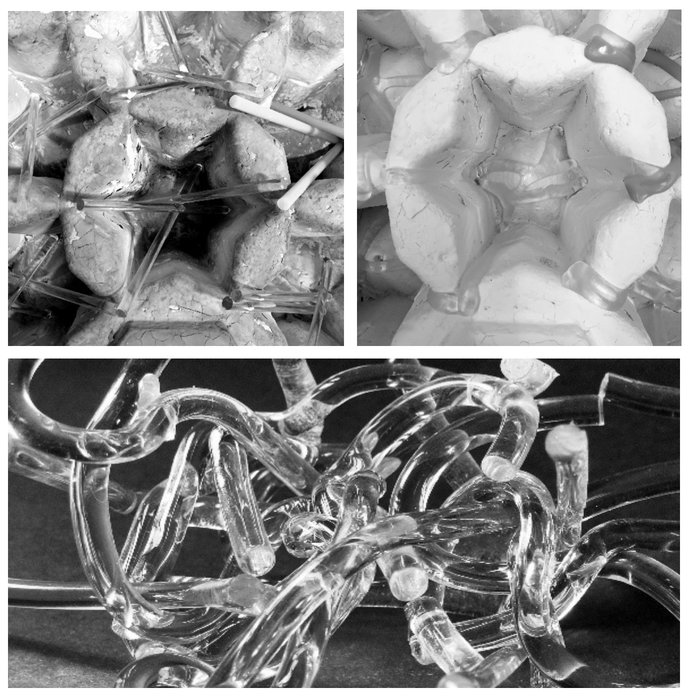

Figure 3: Assistive mold before and after firing (top). Aggregation of irregular modules shown at bottom image. (Images top: Steve Smigielski, Image to the bottom: Georg Rafailidis)

aided the aggregation process, similar to Velcro surfaces. To scale-up this approach to an architectural scale, two additional materials were

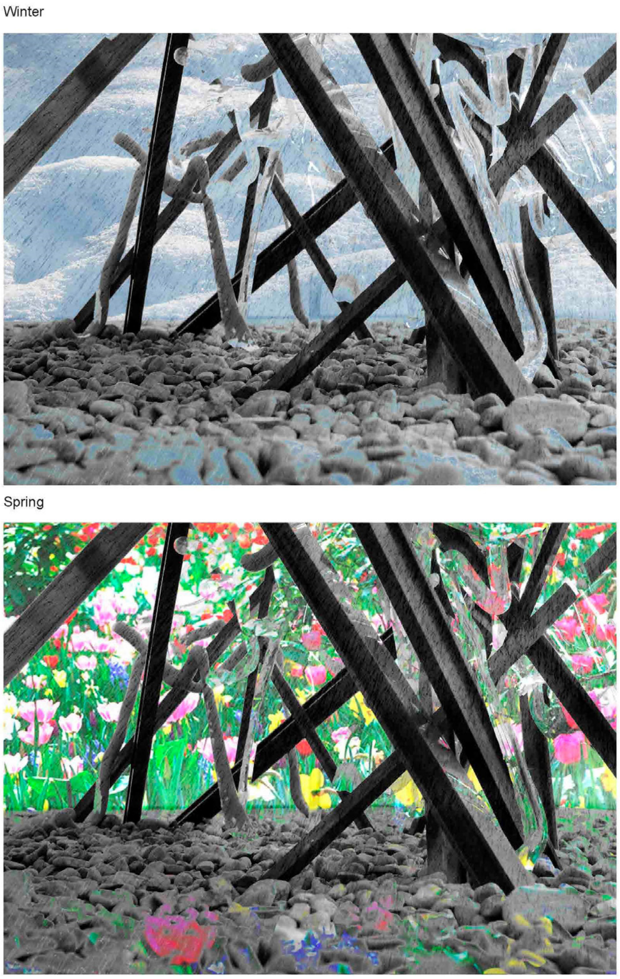

Figure 4: Self assembling spatial proposals with varying seasonal envelopes. (Images: Kim Sass, Steve Smigielski)

introduced. Modules over 2 ft. were made of wood and modules over 8 ft. were made of steel. The construction sequence followed the hierarchy of scales and materials. In the documented model, first, three steel modules with a diameter of 30 ft. are dropped on top of one another. Next, wood modules with an 8 ft. diameter are dropped onto the assembly. The third pour consists of glass modules with diameters ranging from 2 ft. down to 4 in. , creating an outer crust. In contrast to standard constructions, this assembly does not require labor skills, is rapid and needs no fasteners. It is nearly self-assembling. In winter, snow and ice contribute to making a sealed envelope. In summer, growing vines provide shading. Each assembly/pour creates a geometrically different but typologically related structure. The assembly has no required tolerances.

MONOLITHIC GLASS STRUCTURE THROUGH ELECTRIC ARC WELDING (STUDENT TEAM: TARAS KES, ANDREW KIM)

While most projects took glass in various forms, and investigated techniques and formal outcomes of glass forming, the second project documented here investigates the architectural potential of glass making, turning sand or silicon dioxide into a range of vitreous or glassy substances using both the kiln and electric arc welding. This

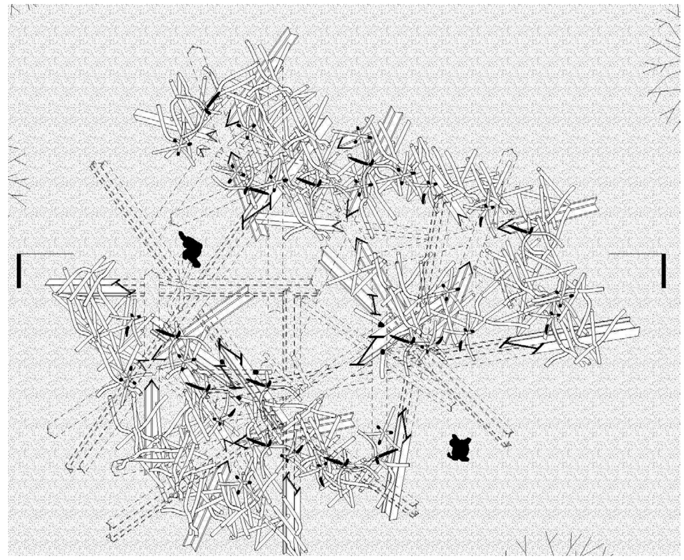

Figure 5: Plan (Drawing: Kim Sass, Steve Smigielski)

type of electric arc furnace was documented in depth by the French chemist Henri Moissan in 1904 (Moissan [3]). Students worked with silicon dioxide or silica, rather than glass, and experimented with various additives including soda ash and lime stone to lower the melting temperature of the sandy mixture, and to save energy. Initial experiments were conducted in a plywood “sandbox” using graphite rods in an electric arc welding process. The electric arc welder can produce temperatures up to 6500 degrees F (approximately 3600 degrees C), which is well above the melting temperature of sand. First tests resulted in fulgurites, small pods characterized by a vitreous interior and a chimney much like those created by lightning found in nature.

In an architectural context, this process opens-up a series of glass-specific potentials and questions:

• Glass making is slow due in-part to long annealing times. Glass making with an electric arc is instant. Are there techniques that make

Figure 6: Typical electric arc fulgurite. (Image: Taras Kes, Andrew Kim)

stable glass artifacts through this process that could eliminate the process of annealing?

• Glass making happens in large industrial settings. Could the electric arc technique allow for localized, low-tech, onsite production?

• Glass elements are typically connected through cold forming techniques like gluing. Could the electric arc allow for glass to be used as an adhesive, creating truly monolithic glass structures?

• Glass could be produced where sand is, avoiding the transport of the raw mate-rial and allowing the monolithic structures to disintegrate back into the natural setting after their use.

The initial experiments investigated different material mixes and used both the glass and ceramic kilns as well as the electric arc for heat sources. Results from the electric arc process consistently produced dark, smooth vitreous bodies encased in sandy shells (fulgurites), whereas kiln-based processes managed to fuse the sand into solid, crumbly swatches, but didn't transform the material visibly into a glassy, vitreous body.

The students continued by conducting experiments into how to modify the shape of the initial, typical fulgurite pod or egg. Tests demonstrated that when the electrodes were close to the sand surface, the hot gasses form a chimney to the sand surface where the gases escape. By placing the electrodes further down in the sandbox, egg shapes or pods are formed with two openings which connect to the graphite rods conducting the electrodes. Tests also demonstrated that the electrodes can be moved after fulgurites are made, to create interconnected, longer, vitreous artifacts. The graphite rods were used together with steel tools to pry-open the fulgurites when their glassy interiors were still molten; the results were patches of dark, multicolored glass with a sandy, crusty under-side. The electric arc was also used to weld these glass patches or pieces together with-out any added material, creating monolithic glass artifacts. Further tests investigated how pre-formed glass pieces could be attached, like glass marbles or glass rods.

The electric arc proved to be a suitable tool to form glass instantly in small batches from raw materials. How could one think of creating

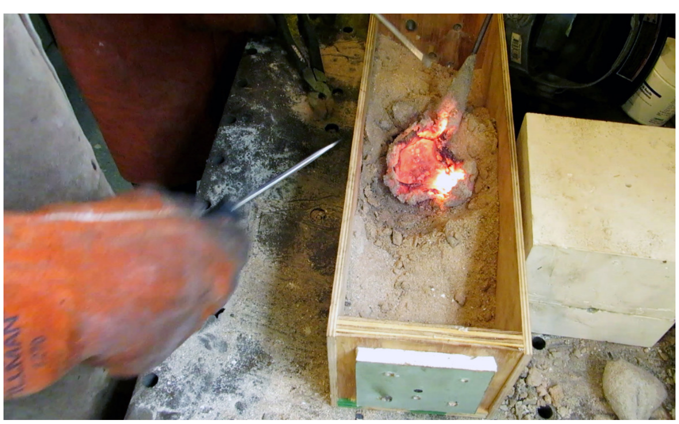

Figure 7: Fusing of glass fulgurites through the proposed electric arc method. (Image: Taras Kes, Andrew Kim)

architectural form from this specific glass fabrication process? If used for fabrication in areas where sand is already naturally occurring (coastal areas, deserts), then it might be helpful to think of sand also as a formwork material to stay true to a pure, monolithic glass concept of construction. Students conducted test to see what forms sand adopts when it accumulates through pouring. When centrically poured, cones form. The angle of the cones vary depending on the humidity of the sand. Dry sand form cones with 30-degree angles. Wet send can generate sand with steeper angles, up to 50-degrees. Electric arc fulgurites can be formed underneath the existing sand surface, withdrawn, pried open, and placed upon the formed sand cones that act as formwork. The glass artifacts would then be welded together through electric welding, forming a monolithic structure that consists of the same material as the surrounding natural environment. By digging out the interior sand, the glass shell remains. Damages to the structure could be repaired using the electric arc technique with the available material onsite. The structure could be demolished onsite by simply breaking it into smaller particles and mixing it back into the sur-rounding sand. Glass has an exceptionally long life span. When not mixed with other material, glass can retain this long material lifespan of thousands of years.

Figure 8: Spatial proposal for a monolithic glass structure. (Images: Georg Rafailidis)

WOOD MOLD AS GLASS JOINT (STUDENT TEAM: KYLE MCMINDES, MATT MEYERS)

The final project documented in this paper is one of the many blow-glass prototypes fabricated for us by the skilled glassblowers and gaffers at the Corning Museum of Glass in Corning, NY. For two years, staff of the Hot Glass Programs at CMoG have worked with us, reviewing drawings throughout the semester, and then fabricating select pieces using molds made with fruit wood, constructed by students. Unlike projects that used the glass kiln, to which students had daily access, projects that involved blown glass prototypes weren't subject to a process of experimentation and trial-and-error through the semester. The experience nevertheless yielded unexpected results that students could extrapolate on through drawings. The project shown here takes both the remains of fruitwood molds and the blown glass components both as part of a structural assembly. Molds – not

Figure 9: Hot glass prototyping of the glass block with respective wood mold/joint at the GlassLab of the Corning Museum of Glass. The wood strips of the mold are used as joints between the six blown glass artifacts. (Image: Georg Rafailidis)

just in glass fabrication, but more widely in many fabrication processes – are often left as the invisible template that defines a form. They might be kept in an archive for further form-reproduction, or, if damaged or "exhausted" after several castings, are often tossed away. This project takes advantage of the fact that a fruitwood mold, in glass blowing, exhausts after, on average, 6-5 glass units are blown. The simple design of the mold allows it to be disassembled into a number of sticks that can be used to form wood joints in a ridged, bulbous glass block assembly. Because the glass is formed directly against the wood, the pieces of wood fit perfectly in the notches of the ridged glass units. Joints, in an all-glass assembly, are an issue because of the hardness and fragility of glass; wood, in contrast, is softer, is more flexible and able to absorb structural stresses. Fruitwood molds, in glassblowing, if they are made out of several pieces, have to be connected mechanically. The fact that the mold is constructed using mechanical fasteners (the sticks are screwed on a baseplate) also makes the disassembly of the mold quick and easy, without causing damage or change to the wood members. The wood joints would offer a number of opportunities in how to use and configure the glass assembly – the assembly could be tied-into a wood primary structure, for example. The combination of the "scrap" pieces of mold wood become an asset in an otherwise very formal and rigid type of construction (glass), enabling a glass construction to be created more flexibly and casually as a wood construction. It also questions the necessity for a material hierarchy in fabrication techniques, in which many fine, re-usable materials are needlessly tossed to produce a certain "finished" object or product.

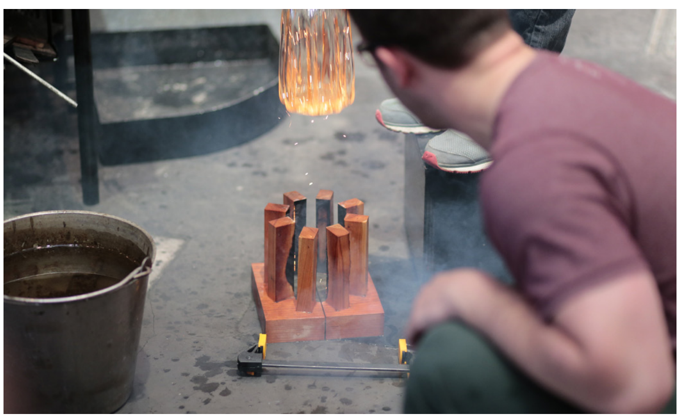

Figure 10: Hot glass prototyping of the glass block. (Image: Georg Rafailidis)

CONCLUSION

An fascination with the seeming inaccessibility of glass as a material for architectural experimentation lead to two years of working with students and glass through a range of techniques, including kiln-formed warm glass, the elemental process of glass making with sand and high heat, and glass blowing with wood molds, at the prestigious Corning Museum of Glass. The original motivation for this experimentation and collaboration was the design of our "Thermometric Façade" unit – a temperature-responsive glass-block unit filled with wax PCM, whose performance relies on an extremely precise interior cavity. Through handling glass and witnessing its behaviors and potentials first-hand through two architectural design studios, we can begin to imagine ways of generating a glass block prototype, a long-awaited proof-of-concept with architecturally true materials. The experiments and design proposals that came out of the glass studios nevertheless stand on their own as design research into a new paradigm for architectural glass as a highly plastic, tactile, elemental and three dimensional material in architecture. In architecture glass is typically used for being invisible and flat. Architectural glass either disappears through transparency or by reflection. It is typically not considered suitable as a structural element and is regarded as an energetic "problem" due to low insulation values. The documented projects question these architectural preconceptions. The rich history of glass fabrication and glass components, as well as contemporary material developments suggest alternative readings of glass, as a material with a much more maleable and variable materiality than generally thought.

ENDNOTES

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Research-Based Design and Green Buildings: Interdisciplinary Collaboration Between Students, Faculty and Practitioners

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Over the past five years, faculty in the School of Architecture at Portland State University have been awarded four grants totaling over $1,000,000 to transform green building education with an emphasis on interdisciplinary experiences, research-based design and collaboration with practice. This paper highlights the progress and lessons learned from three interrelated programs: the Research-based Design Initiative, the Building Science Lab to Advance Teaching and the Green Building Scholars Program. Issues discussed include barriers to conducting collaborative green building research between the academy and practice, the challenges of interdisciplinary coursework, and how these programs could be a model for other universities.

INTRODUCTION

Buildings consume 41 percent of the primary energy and are responsible for 40 percent of carbon dioxide emissions in the US.[1] These numbers exclude the significant environmental impact of manufacturing, transporting, installing, maintaining and eventually demolishing materials used in building construction.[2] While every other sector has been reducing energy use over the last 30 years, commercial buildings have increased their energy intensity (energy use per square foot) by over 8%. It is well documented that deficiencies in building performance are ubiquitous, and if addressed nationally in the US could contribute to over $18 billion in savings annually.[3] Thus, to mitigate climate change, there should be no higher priority than ensuring that buildings are created, adapted and retrofit to minimize energy use, resource consumption, and cost. One primary approach to high-performance or green building design and construction is to utilize rules of thumb and rating systems that have been found to provide no guarantee in reducing actual energy consumption below current averages.[4] These methods alone are no longer sufficient as society demands net zero energy and carbon buildings - not just incremental improvements in building performance.

Instead, design decisions must be based on a combination of robust scientific knowledge and applied research. The greatest opportunity for research is in academia where there are resources available to test pressing questions related to the design and engineering of green buildings.

Interdisciplinary collaboration between engineers and architects during the design and construction of a building is also critical to the reduction of energy use and the delivery of green buildings.[5] However, there is little if any interaction between architecture and engineering students during their education, and there are a number of barriers to interdisciplinary courses and programs in academia.[6] Green building "charrettes," collaborative meetings of stakeholders early in the design process to discuss engineering and design strategies to reduce resource use, are common in professional practice. However, the efficacy of these charrettes is limited by numerous barriers between participants of different disciplines, including disparate value systems and terminology.[7] As members of the building industry are highly influenced by their early training, one way to overcome these barriers is by offering opportunities for engineering and architecture students to take building science courses in other disciplines and have meaningful and substantive experiences together during their education. This will allow individuals to better understand the language, motivations and biases of each discipline in order to become more effective collaborators in the future. The Royal Academy of Engineering recently released a report arguing for the urgent transformation of engineering education to emphasize multi-disciplinary research in building design, engineering, energy and carbon efficiency and the need to recruit the best engineers of each generation to reduce the environmental impact of buildings.[8]

To address both of these issues, Portland State University's (PSU) School of Architecture has been awarded four grants totaling over $1,000,000 to generate translational building science research in collaboration with local architecture and engineering firms and promote interdisciplinary educational efforts. The result is a combination of highly specified interventions and course development that ensure students will be effective researchers, collaborators and leaders when they are part of multidisciplinary teams in practice.

EXISTING MODELS

There are several models practiced throughout the US for aligning academic architectural research with the needs of practice. Evidence based design is "the process of basing decisions about the built environment on credible research to achieve the best possible outcomes."[9] With particular emphasis on human health metrics, evidence based design aligns itself with the healthcare industry. Evidence based design research can be found in interdisciplinary university centers such as the Center for Health Systems and Design at Texas A&M and the PhD Concentration in Evidence-Based Design in the School of Architecture at Georgia Tech.

To distinguish itself from the established field of evidence-based design, research-based design is a generalized term used to describe research focused on reducing the environmental impact of buildings. Research-based design "uses quantitative data collected from existing buildings, generated through rapid prototyping and testing, or simulated using parametric and genetic computer modeling to reduce resource consumption through improved design."[10] In academia, research-based design is typically deployed in one of three ways. Research-based design can be (1) used to promote research skills relevant to practice in academia, (2) generated in university laboratories supported by professional consortium, and (3) found when the academy acts as a consultant.[11] While each of these are successful in generating research-based design, there exists a need for more direct application of research into architectural practice.[12] Additionally, these methods provide few opportunities for students to collaborate in an interdisciplinary environment.

Within the discipline of medicine, there is a successful relationship between research and practice. Known as translational research, results from laboratory research and tools from academia are applied directly to practice. Implementation of translational research is argued to improve building science education and practice.[13] It has the potential to increase adoption of new software, tools and strategies in the building industry, break down disciplinary barriers, and practicing professionals have the ability to influence research agendas in academia.[14]

Three models have been proposed for translational research in regards to architectural education and practice. These models include: (1) practice embedded in the academy (2) the academy embedded in practice and (3) collaboration.[15] These models (or a combination of these models) are currently implemented in the academy with examples found at RMI's Center for Architecture Science and Ecology, University of Minnesota's MS in Research Practices, and Portland State University's Research-based Design Initiative. This paper focuses on the advantages, challenges, and evolution of the Research-based Design Initiative (RBDI) to utilize translational research and interdisciplinary collaboration as a means to encourage better building performance.

RESEARCH-BASED DESIGN INITIATIVE (RBDI)

Initially funded through an National Council of Architectural Registration Board (NCARB) grant with subsequent funding through a $100,000 five-year grant from the Oregon Community Foundation and $40,000 in contributions from participating firms, Professors Corey Griffin and Sergio Palleroni transformed two graduate level building science and technology courses from lecture and case study based seminars into practice and research oriented courses. The goals of the RBDI set out in the original NCARB grant proposal are as follows: (1) Expose architecture students to various models for multidisciplinary collaboration by embedding them in professional design teams. (2) Provide architecture students with the opportunity to lead an interdisciplinary team of peers. (3) Generate original sustainability research to assist practice with pressing needs and improve the public health and welfare.

The faculty instructors of these courses, continued to ensure students are given the content required to meet National Architectural Accreditation Board (NAAB) and departmental standards, the outcomes and deliverables of the course shifted to focus on multidisciplinary collaboration and original sustainability research relevant to practice. Advanced Building Structures, an elective seminar, was the first pilot for this new methodology in Winter 2012. Advanced Building Technology, a required course for students entering the Masters of Architecture program, and Advanced Building Structures (later renamed - Building Science Research Methods) expanded these efforts in Fall 2012 and Winter 2013.

Currently, the RBDI is a series of on-going, graduate level seminars that revolve around two primary activities: (1) architecture and engineering students conduct building science research of relevance to a project in an architecture firm and (2) students are embedded in project teams where they attend all interdisciplinary meetings for the course of a term to witness and document interdisciplinary collaboration. Students now also have assigned space in the firm's office in improve collaboration with the firms. In this unique way, students become contributing members of a design team and building science experts on issues relevant to current practice. For the architecture firms involved, working with universities allows practicing architects the ability to utilize a deeper level of research expertise in the design process and access resources not typically available in practice. Academic terms conclude with research symposiums where students present their work to representatives from all of the participating firms, creating a dialog around pressing building science issues with students, faculty and practitioners.

ROLE OF FACULTY, FIRMS, AND STUDENTS

Imperative to the success of the RBDI is the collaboration of each party involved (faculty, firms, and students). Each party has dedicated responsibilities, roles, and active relationship with the other parties (figure 1). Faculty are responsible for general coordination including the setup and execution of the initiative. Faculty meet with practitioners before the beginning of the academic term in order to elicit feedback on past projects and suggestions for research projects. At the beginning of the term, faculty select which students are to be assigned to which research project, taking student preference, skills, and opportunities for interdisciplinary collaboration into account.

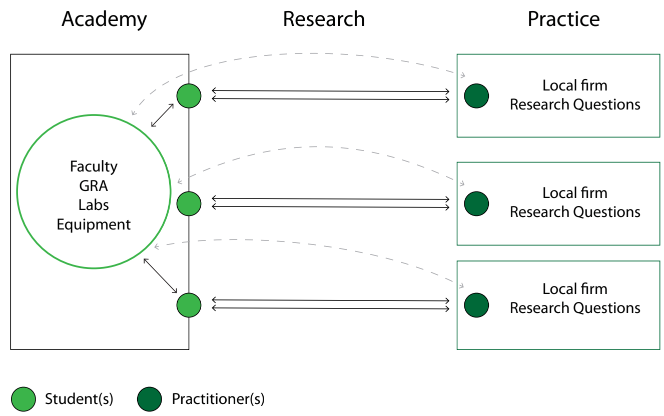

Figure 1: Research Based Design Initiative Organizational Diagram

Once the term begins, faculty assist students by providing resources such as access to software and lab equipment on campus as well as feedback on the research through individual meetings and class assignments.

Firms are responsible for proposing projects and providing assistance to students. A practitioner or group of practitioners at each firm identify research projects and topics that can be related to a project under design or are not depending on the timing of the academic term and project schedules. During the term firm representatives are responsible for meeting with the student(s) regularly and ensure they are included in all multidisciplinary meetings and witness to other forms of interdisciplinary communication (e- mails, conference calls, etc.).

During the research project, architecture students work as part of an interdisciplinary team of peers when possible and generate original sustainability research relevant to the firms and project team of which they are a part. Students are responsible for the integrity of the research and document progress in the form of weekly memos. Weekly memos serve two functions. They document collaboration efforts and current state of the research project, and memos create a record students can use to generate "timelines" presented at the end of the term with their research. Both the memos and timelines are used by faculty and firms when evaluating research projects.

RESULTS OF RESEARCH

To date, research engendered from the RBDI can be categorized into three types and five topics. The three types of research include simulation, post occupancy analysis/field research, and precedent research. Simulation enables rapid testing of design iterations, and students with simulation research projects regularly present not one, but many different iterations of the design project. These iterations are largely visual, including quantifiable metrics on simulated performance through a specified software.

Post occupancy analysis/field research include point in time and/or extended data collection of the built environment for validation of past design decisions. Building science tools used to collect data include infrared thermographers, time lapse cameras, sound meters, light meters, occupancy sensors, temperature and humidity sensors. Post occupancy research is not only useful for validation but also applicable to future design projects of the firm. Precedent research involves literature and case study research on topics and cutting edge technologies that the firm has yet to have significant experience with.

Research topics include building envelopes, structural systems, daylighting/solar gain, ventilation (natural and displacement), and building retrofits (figure 2). Topics vary from year to year, term to term, with envelopes and daylighting/solar gain being most common. Firms can gravitate towards one research topic. For example, a firm may be particularly interested in studying daylighting regardless of project, research type, or student group.

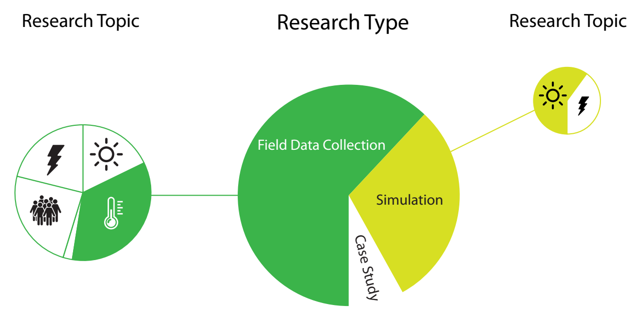

Figure 2: Research Breakdown 2015-2016

STAKEHOLDER FEEDBACK FOR RBDI

Feedback about the RBDI was gathered through a combination of surveys and in-person discussions. Surveys are distributed to firms and students on an annual basis and include closed-ended and open-ended questions. In-person discussions with the practitioners involved happen before, during, and at the conclusion of each academic term to provide additional feedback. With regards to the three goals of the RBDI, the general opinion is favorable and the majority of individuals felt the goals of (1) collaboration, (2) interdisciplinary groups, and (3) translational research had been well met (figure 3). Additionally, the RBDI has regularly been appreciated for the dual benefit it has for firms and students. In his feedback, one practitioner summarized the unique value of this collaboration: "Throughout my involvement with the PSU RBDI, I have been struck by the unique opportunities it offers to students to directly engage in active projects and offer actionable feedback that can impact the final project designs. For firms the RBDI provides access to engaged and motivated students who can dig into issues that the design team may not have the personnel resources to fully explore. It also is an opportunity for firms that ask questions that may be tangential to project completion (new tools, new process) but can inform later work."

While the goals of the RBDI were met, there has been and still is room for improvement. "Interdisciplinary collaboration" has the weakest indication of success. This primarily stems from the challenge of recruiting engineering students to take architecture coursework.

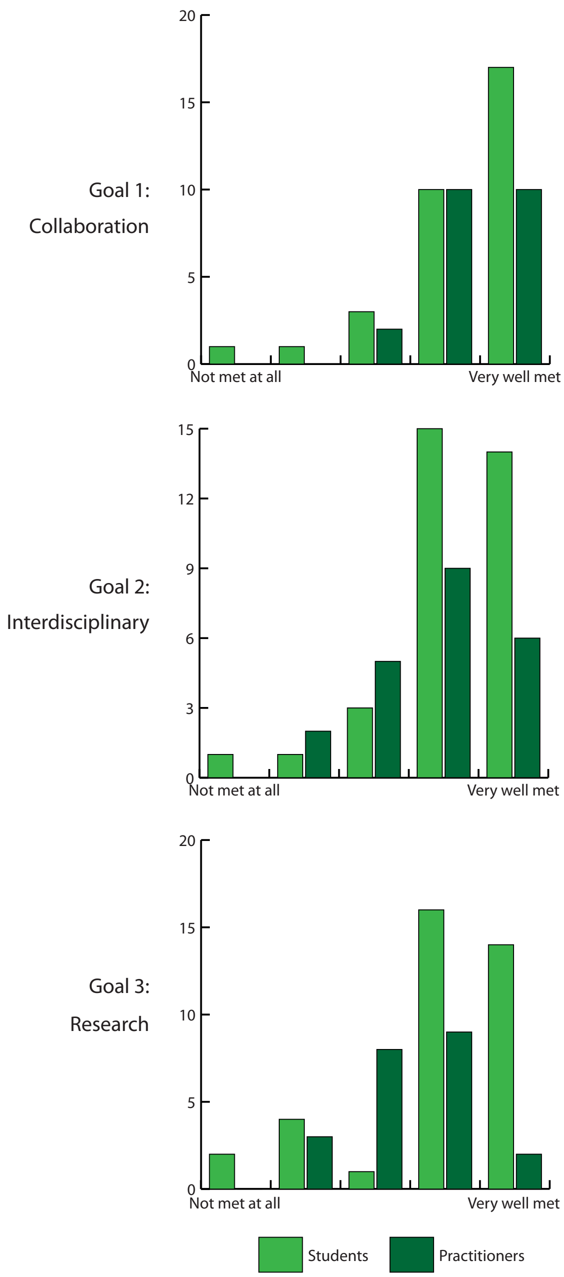

Figure 3: Feedback on Goals met for Research Based Design Initiative

Given the rigorous demands of architecture and engineering degree programs, there is little space or time for students to take classes they do not count toward their degrees. As Portland State University is an "access" university, it charges tuition by the credit hour providing additional financial barriers for students to take elective coursework. To overcome these barriers, faculty in Architecture, Civil Engineering and Mechanical Engineering at PSU applied for and received a grant from the National Science Foundation to encourage students at all levels to study building science. This program will be discussed in more detail later in the paper.

Additionally, the quality of the student research was not always as high as desired. This is due primarily to the students' lack of previous research experiences and building science knowledge. The graduate seminars used in the RBDI have no prerequisites; consequently many students are simultaneously learning basic concepts and applying them to a research project simultaneously. Firms and students have found the research could end up being an opportunity to learn how to conduct building science research rather than provide a research result that significantly impacted design decisions in practice.

OUTCOMES OF RESEARCH BASED DESIGN INITIATIVE

There are a number of positive outcomes and lessons learned from these seminars over the past five years. As the first course in the RBDI is required, all graduate architecture students at Portland State University are trained with research skills applicable to advancing professional practice. Each graduate student also acquires experience working with a local architecture firm. Firms have the benefit of students conducting research for their office. The semi-annual symposium is particularly rewarding as research is shared between firms and larger questions about advancing the role of research in practice are regularly discussed. A number of students have been hired by the firms they have worked with to continue their research in a full time internship over the summer as well as offered full-time positions once they graduated.

A number of drawbacks hinder the progress and ease of implementation for the RBDI. Drawbacks include academic term influencing scope of research project, limited time and resources for faculty, limited availability of resources for students, and quality of research. Drawbacks such as length of academic term can not be helped. Other drawbacks, such as time and resources, can be dramatically reduced with additional funding to increase availability, dedicated staff support, and additional resources. The most problematic drawback is the quality of research. Overarchingly, both firms and students agree research skills are not as high as they would like. To address the lack of research skills, Professor Griffin received a grant to incorporate building science research experiences in undergraduate coursework and develop a new teaching lab, Building Science Lab to Advance Teaching (BUILT).

BUILDING SCIENCE LAB TO ADVANCE TEACHING (BUILT)

Based on the outcomes of the RBDI, Professor Griffin recognized the need for a new lab to be located within the School of Architecture that was dedicated to educating students on building science with particular emphasis on building science research skills. In late 2014, Professor Griffin was awarded a $300,000 W.M. Keck Foundation Undergraduate Research grant to create the Building Science Lab to Advance Teaching (BUILT). BUILT promotes early development of building science research skills in higher education by exposing students to hands on, collaborative building science research activities. Geared towards undergraduate students, BUILT provides students and faculty members resources including a physical lab with space to host seminars, a tool lending library, and dedicated staff (figure 4). As a teaching lab, BUILT is equipped with computers, sensors, design-simulation software and fabrication tools for the research and analysis of existing building performance and testing of proposed designs. In addition, the lab has a large conference table where students and faculty can hold either impromptu or planned meetings, classes and events. BUILT staff hold regularly scheduled open hours for the lab. During those times, students can come ask questions, receive one-on-one training, and check out equipment.

At BUILT there are over 250 pieces of equipment available for student checkout. BUILT's tool lending library is comprised of building science tools that collect point-in-time and/or prolonged building performance metrics including light, temperature, wind, sound, etc. As students may not have prior knowledge of tool use, tools are specifically selected for their ease of use in observation, collection, and retrieval of data. For example, BUILT makes use of the Vernier LabQuest2 hardware that is designed for K-12 as well as university science lab settings. It consists of touch screen base station and external sensors that are plug and play. The LabQuest is both a tool for taking in situ measurements as well as a data logger that can easily export data by e-mail. In addition to tools, BUILT has an extensive simulation software library students can "check out" through reservation of 1 of 4 lab computers.

BUILT promotes new teaching models for building science education by embraces active learning exercises as a means to introduce building science concepts and research methods into traditional classroom

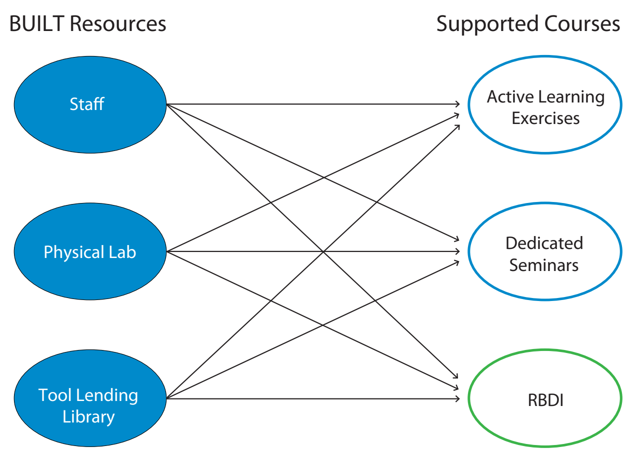

Figure 4: BUILT resources and support diagram

environments. BUILT supports these active learning exercises by providing resources such as a building science knowledge base, the development of handouts and worksheets, specifying appropriate tools, assist with tool check-out and use, and deliver in-class lectures on building science. Additionally, BUILT supports dedicated building science courses. These courses have significant research components and introduce students to new building science tools and methods. While BUILT is tailored towards undergraduate student body, BUILT's staff, lab, and tools are available to RBDI students, faculty, and firms. By supporting a variety of courses, student-led research, and active learning exercises, BUILT fosters skills critical for future professionals as we move toward a more collaborative and sustainable future.

BUILT FACULTY FELLOWS

Faculty that wish to receive assistance with course development apply to become BUILT Faculty Fellows. During application, faculty propose the initial concept of an active learning exercise, specifying intended audience and course the exercise is to be located within. Once the application is approved, BUILT Faculty Fellows receive a stipend of ($5,000) and BUILT resources to develop and deploy the active learning exercise.

As a BUILT Faculty Fellow, faculty receive all BUILT resources including staff and purchasing tools appropriate for the intended audience and subject matter. BUILT staff works with the BUILT Faculty Fellow to refine the active learning exercise in such a way that it utilizes hands-on research to reinforce course material and introduce building science education. Once the active learning exercise is clearly defined, BUILT takes the lead on selecting appropriate tools, developing handouts and worksheets with regular feedback from the BUILT Faculty Fellow. During the deployment of the exercise, BUILT staff is available for tool training, check-out and in-class tutorials including introductory lectures on building science.

Through BUILT Faculty Fellows, BUILT reaches a diverse range of students in a wide spectrum of courses. To date, BUILT has active learning exercises in three large, lecture based courses: (1) an introductory (freshman) level course on environmental design open to all majors, (2) the second course in the architectural history sequence typically taken second year (sophomore), and (3) the third course in the architectural history sequence typically taken second year (sophomore). Additionally, BUILT resources are utilized by three seminar courses: (1) a sophomore-level seminar focused on introductory building science principles and research methods with an interdisciplinary group of architecture, urban planning, and engineering students, (2) a senior-level architecture seminar focused on the application of building science to multi-family housing with an emphasis on climate-responsive design, contemporary wood structures and enclosure systems, and (3) a senior-level mechanical engineering course on air quality. The overarching goal of BUILT is to create a scaffold of undergraduate building science research experiences throughout all levels of the curriculum to develop skills and knowledge that will allow these students to conduct research in practice as well as advance much further in the RBDI supported graduate-level seminars to benefit of firms and the profession at large.

RESULTS OF BUILT

Since BUILT's inception, student exposure to building science research opportunities has more than tripled (figure 5). Approximately 400 students will have participated in BUILT supported active learning exercises by end of spring term 2017, and approximately 40 undergraduate students will utilize BUILT resources in seminars dedicated to building science education. When students that participate in the RBDI is added to undergraduates exposed to building science and research-based design through BUILT, the total number of students exposed to architectural research is anticipated to be over 460 on an annual basis in the coming years.

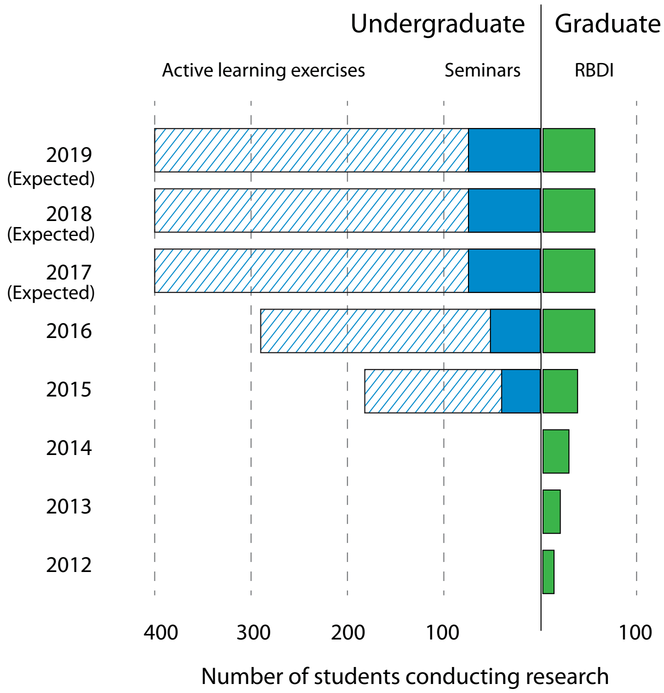

Figure 5: Quantity and methods for student-led research

OUTCOMES OF BUILT

BUILT expands efforts of the RBDI goals for students to collaborate, work in interdisciplinary groups, and perform student-led building science research by providing research opportunities to students earlier in their education in order to strengthen their building science knowledge and research skills. All aspects of BUILT have been successful so far, with particular success in active learning exercises engendered through partnerships with BUILT Faculty Fellows.

BUILT is an in-house resource for students and reinforces its support by hosting events such as the most recent RBDI symposium. In addition, the expanded curriculum supported by BUILT positively impacts the RBDI. As mentioned, not only are students more prepared to conduct quality research by the time they enroll in the RBDI courses in graduate school, but research conducted at the undergraduate level has positively influenced local firms to join the RBDI.

The most surprising outcome of BUILT is the impact BUILT has had on courses not directly involved with BUILT. Students with previous experience participating in a BUILT active learning exercise or enrolled in a dedicated course return to BUILT seeking tools and advice to solve problems in other coursework - specifically in architectural design studios. These students most frequently come in the beginning of studio, but have been known to come around midterm and pre-finals with last minute questions.

While the number of students conducting building science research has expanded, interdisciplinary groups continue to be difficult to implement. Engineering continues to be under-represented in courses and BUILT related activities. Additionally, while exposure has increased, the number of students specifically studying building science has not. As such, drawbacks in interdisciplinary group work and lack of students with a special interest in green buildings hinder the progress of translational research and sustainable education at Portland State University.

GREEN BUILDING SCHOLARS PROGRAM

To increase interdisciplinary, research-based design opportunities for students studying green buildings, Professor Griffin along with other faculty from Architecture, Civil Engineering and Mechanical Engineering received a grant of $630,978 from the National Science Foundation's Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program. The program focuses on increasing student diversity in STEM disciplines through a combination of scholarships, curricular and co-curricular activities that support recruitment, retention, student success, and graduation. At PSU, the grant funds the Green Building Scholars (GBS) program that provides scholarships to increase the number of architecture and engineering students studying building science in *interdisciplinary* coursework over a period of five years. The grant enabled new educational opportunities focused on reducing the environmental impact of buildings. Three competitive scholarship tracks - (1) freshmen of all majors, (2) juniors/seniors pursuing a B.S. in Architecture, Civil Engineering and Mechanical Engineering and (3) Master's students in those majors - reach students at different points in their education, aligning with admissions processes. Stepped scholarship amounts in each provide an increasing incentive for students to continue their interdisciplinary study of building science. This program will provide a large incentive for students with a strong foundation in building science and financial need to pursue graduate studies where the bulk of advanced building science courses are taught and research is conducted.

Students that receive the scholarship are known as "Green Building Scholars" and enroll in courses focused on green buildings and building science. In addition, Green Building Scholars get unique extracurricular opportunities including special building tours, small group discussions with upper management of architecture and engineering firms, and field trips to experience iconic green buildings/firms/cities. Scholars also have the opportunity to participate in the mentorship program where upper-level Scholars are paired with a local professional in order to develop a relationship and ask questions to like-minded individuals in the work-force. In this way, students are exposed to contemporary issues, research and work opportunities pertaining to green buildings.

RESULTS OF GREEN BUILDING SCHOLARS PROGRAM

Now in year three of five, the GBS program has awarded scholarships to 58 students toward a target of 108 students total by the end of the grant. Of the 15 scholars who have graduated, over half are pursuing an advanced degree (Masters or PhD) and the remainder are all employed in architecture or engineering fields related to green buildings and infrastructure. The demographics of the scholars is far more diverse than the general populations of the three disciplines with women making up 45% of scholars, and under-represented minorities comprising over 40% of scholars. Most importantly, the number of architecture and engineering students taking a green building or building science course outside of their major has increased three-fold since the inception of the GBS program.

OUTCOMES OF GREEN BUILDING SCHOLARS PROGRAM

As the first NSF S-STEM grant to include architecture students, faculty and coursework, the GBS program can serve as a model for nationally funded STEM education efforts to include architecture. At PSU, the GBS program has been critical in opening a dialog between departments about how to best provide interdisciplinary experiences for students. This has led to certain upper-division architecture electives being counted toward engineering degree requirements and providing paths for architecture students to attain prerequisites to take engineering coursework. One goal of the GBS program is to create a minor and graduate certificate in Sustainable Building Systems to formalize the pathways for students to complete an interdisciplinary course of study around the topic of green buildings.

CONCLUSION

While it is clear that society must reduce the environmental impact of buildings to mitigate climate change, how to do it is not as straightforward. This paper has outlined three interconnected programs at PSU that strive to not only prepare architecture and engineering students to meet the challenges of creating high-performance, low-impact buildings, but also impact professional practice right now by providing research, expertise and resources to improve projects currently under design that these firms wouldn't otherwise have access to. In order to overcome disciplinary silos and institutional barriers, the four grants received proved to be a significant catalyst in encouraging dialog across disciplines and administrative offices. The grants themselves provided resources in (1) scholarships for a diverse, interdisciplinary cohort of students to study building science, (2) equipment and staffing to support the creation new green building research experiences throughout the architecture curriculum, and (3) staffing to coordinate dozens of research collaborations with practice each year.

It remains unclear if the research-based design efforts detailed here will be successful once funding for the three programs ends in two years. All of the grants were intended to be transformative, one-time opportunities, and it is much harder to find grants to sustain ongoing educational efforts. As mentioned earlier, the authors are in the midst of creating new academic programs to formalize the interdisciplinary coursework and curricular paths that have been established. Fortunately, while the architecture firms did not initially contribute financially to the RBDI for the first three years of the program, all of the participating firms now contribute annually, and there is a goal to increase the number of architecture firms participating to increase funding from practice to offset the loss of grant funding. As practitioners with an existing relationship with the RBDI move from one firm to another, there is an expanded network of people to champion this model for architectural research in more firms.

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