Storm Resilient Design with Precast Concrete: New Practices, New Knowledge Networks

"...there is no longer a distinction between material and form...design is just a moment within a continual state of material flow..."

—Hiroshi Ota

MATT BURGERMASTER
New Jersey Institute of Technology

A RESPONSE TO THE REAL: BETWEEN SERVICE AND AGENCY

In the past two decades, university architecture programs have been concerned with how design education and research should respond to the radical and widespread technological, social, and environmental changes taking place around the world. These paradigm-shifting transformations - including the spread and intensification of globalization, the ubiquitous use of digital technologies, and the unavoidable exigencies of ecological mandates – have had major impacts on the design of today's built environments, as well as the professions involved in such activities. The emergence of this 'new normal' situation has been the subject of much discussion and debate in the professional architecture, engineering, and construction (AEC) industries, as well as within the academic communities they are affiliated with. The 2011 ACSA Teacher's Seminar, titled *Performative Practices: Architecture and Engineering in the 21st Century*, directly focused on the shared challenges and opportunities for architecture and engineering academic programs amidst the emergence of new realms of expertise, models of collaboration, and changing professional roles needed to match them. The conference organizers proposed the following:

> *"...the modern era of technology, characterized by tools, instrumentality, and function, gave way in the late twentieth century to the age of systems, characterized by complex configurations, self-organization, and emergence…New practices are emerging from partnerships of architects, engineers, and others that blur disciplinary boundaries and advance new techniques in design and construction. Yet in architecture and engineering schools, the strictures of traditional curricula and funding structures for faculty and research prevents the same kind of vital professional promiscuity. Ecological, economic, and professional realities demand alternative models."*(1)

Along with this call for alternative forms of design education to more effectively respond to current needs, comes the critique that academic institutions are not

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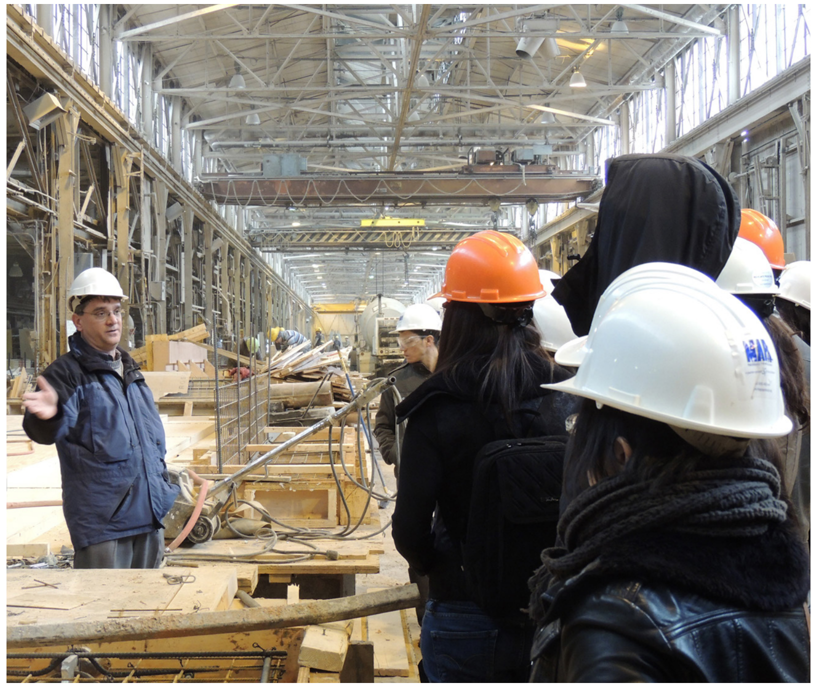

Figure 1: Plant tour, Universal Concrete Products

adequately keeping pace with the broader transformations underway in both practice and industry. Indeed, as the design disciplines are increasingly faced with the prospect that 'good' standard practice may not be 'good enough', the demand for more wholistic approaches to the design of the built environment have emerged. With a new understanding of the interconnectivity of all things now accompanying the end goal of producing minimal footprints, these new realms of complexity not only necessitate an expanded array of contemporary practices, aimed at creating wholes that are greater than the sum of their parts, but also alternative ones. Indeed, the building solutions of the future will depend upon more creative, critical, and collaborative problem-solving than in the past. Here, academia can play a central role in architecture's response to the real, not only in servicing professional industry and practice by training tech-savvy, sustainability-minded graduates, but by creating new knowledge networks that actively participate in the advancement of our discipline's agency to address real-world challenges of the future.

THE PCI ARCHITECTURAL DESIGN STUDIO: INDUSTRY-SPONSORED, PUBLICLY-ORIENTED

The PCI Architectural Design Studio at New Jersey Institute of Technology (NJIT) is an academic program organized in collaboration with building industry sponsors the Precast/Pre-stressed Concrete Institute (PCI) and the Mid-Atlantic Precast Association (MAPA). This program creates new learning networks that combine education and research activities into a single student experience. The program provides a unique opportunity for exploration of high-performance precast concrete design at an advanced level of creative inquiry, design integration, and technical resolution. Students learn about specific precast concrete materials and systems, fabrication and installation process, and technical documentation in an experimental, design-oriented setting. With these professional industry partners, a more robust, collaborative learning environment is created aimed at training future leaders in the field, as well as developing new knowledge and products. Activities include guest presentations by industry professionals, field trips to precast concrete facilities, and the provision of technical resources to all students for use in their class work. This program is offered as an advanced architectural design studio course to upper-level undergraduate students in their 4th year of study, within a 5-year professional degree program. The program's pedagogical objectives aim to:

- introduce students to the precast concrete industry's body of knowledge, including its materials, components, and systems, fabrication and installation processes, and technical documentation.

- apply this specific knowledge to general design problems ranging in scale from building parts, to whole buildings, to multi-building complexes and site designs.

- create innovative design solutions and design research in the field of resilient design using advanced precast concrete technologies that tests their viability in the public realm and marketplace

The PCI Architectural Design Studio at New Jersey Institute of Technology is sponsored by the Precast/Pre-stressed Concrete Institute, a national industry trade organization representing the precast concrete/pre-stressed concrete industry, whose mission is to develop, maintain, and disseminate the body of knowledge necessary for designing, fabricating, and constructing precast concrete structures. As part of that larger industry mission, PCI's educational affiliate, the PCI Foundation, promotes mutually beneficial exchanges of knowledge between industry and academia through educational and research initiatives focused on innovative approaches to the integrated and sustainable use of precast concrete design, fabrication, and construction.

While renowned for its constructive 'brawn', technical advantages, and economic benefits, particularly in structural applications and infrastructural project types, precast concrete has had a comparatively limited, or at least less-recognized, application in design-oriented, architectural projects. PCI Foundation Chairman Tom D'Arcy notes the value of its initiatives to the industry, in the context of this issue of public perception and marketing: *"Having a superior product, that is durable, has better overall quality, and the ability to be manufactured off site and under controlled conditions isn't enough. We need to ensure that tomorrow's clients are savvy about precast concrete design. We need to educate design professionals to ensure our future."* (2) To this end, the PCI Foundation has been sponsoring design studios since 2007 with the goal of introducing precast concrete systems to the next generation to help advance the industry forward towards a new era of application and innovation. New Jersey Institute of Technology is 1 of 7 universities in the United States that currently have a dedicated precast concrete design course in its curriculum in either the school or architecture, engineering, and sometimes as an integrated program for both schools. The PCI design studio's program coordinator is Matt Burgermaster, NJIT Assistant Professor, and the program is run in close collaboration with Greg Winkler, the Executive Director of MAPA, PCI's regional affiliate.

Although focused on the precast concrete industry's specific body of knowledge with the goal of challenging conventional types of design thinking and construction practices, NJIT has expanded its program scope. Within the post-disaster context of Hurricane Sandy, its semester-long investigation of a single material type (concrete) and construction process (prefabrication) also focuses its efforts to towards an urgent societal need - resilient building solutions. To this end, PCI studios have been run in collaboration with NJIT's Center for Resilient Design, a new multi-disciplinary center whose mission is to provide residents, businesses, government officials, and design professionals with actionable designs and expertise for disaster recovery in areas affected by Hurricane Sandy and/or those that are potentially at-risk in the future. This work is focused on the development of building solutions with the capacity to withstand, and adapt to, the destructive forces associated with storm events, as well as future conditions associated with sea level rise. In New Jersey, amidst immediate recovery and re-building efforts, this global challenge of re-imagining the long-term future of communities with high coastal vulnerability is a local reality. Its unique collaboration with the precast concrete industry has been an important asset in helping to merge educational and research activities that create useful knowledge and solutions for students and communities alike. Through the Center, a number of efforts have also been made to disseminate specific precast concrete industry knowledge to the professional design community and general public alike. The studio regularly makes public presentations of its work both at the College and within the communities its projects are based with the goal of sharing its work with broader audiences. These events have included the NJ Mayor's Summit on Resilient Design, at NJIT, and conferences held in coastal communities in NJ, such as a presentation at the annual meeting of Downtown New Jersey, "Recovery, Revitalization, and Redevelopment" and the symposium "Storm Resilient Design for the Jersey Shore", sponsored by the Mid-Atlantic Precast Association.

NEW ECOLOGIES OF CONSTRUCTION

Architectural practice is rarely tasked with solving singular problems nor does it operate outside of the expansive, inter-connected material, environmental, and human systems associated with the specific circumstances that both enable and constrain its production and performance. It operates amongst complexities and multiplicities. One such condition is the emerging field of resilient design.

This studio's industry partnership is aimed at creating multi-valent and productive synergies between "next-gen" precast concrete building systems and the broader field of considerations associated with resilience. Sandy showed us that expecting the unexpected - and building accordingly - will be a key part of such activities. In response to this paradigm shift, comes the need for more strategic, long-term solutions that proactively address the potential risks to people, property, infrastructure, and natural resources. Resilience requires a particular kind of design response to complexity and change. In a resilient system, change is not taken to be a negative force, but rather has the potential to create novelty and innovation. There are different approaches to the design of such systems which aim to resist destructive forces and mitigate impacts, on the one hand, or to adapt to such forces and minimize their impacts, on the other. Accordingly, resilient building systems should not only be stronger, but should be organized and operated differently. Such systems depend upon networked parts that share interdependencies across spatial and temporal scales. Like other resilient structures - those of natural ecologies for example - their organization is designed to maintain critical functioning, even when individual parts fail. Unlike traditional design and construction practices, however, a resilient approach treats a building as an interdependent, adaptive system as opposed to an accumulation of separate components, the result of dissimilar processes, or creation by independent authors. In short, that a building whole be greater than the sum of its constituent parts and that it perform that way. As normative practices and typical ‘off-the-shelf’ building parts, assemblies, and systems may be subject to more stringent, high-performance design criteria in the future, they are prime candidates for reinvention. To this end, students explore the part-to-whole relationships of architecture’s constructive anatomy with a workflow that moves laterally across scales from the design of individual building components to shared site infrastructures, focused less on the objects of design, but rather on their mutual spatial, social, and ecological dependencies. These new “ecologies of construction” frame the program’s discipline-centric design pedagogy that reverses the traditional design-to-construction process by starting with a building’s smallest parts. The typical course of study is organized as a sequential, semester-long working process of starting with, and scaling up from, the design of a singularity (material + component) and moving towards larger, more complex formations (building + site systems). It is organized as 4 inter-related phases of work and deliverables, with specific tasks, learning objectives, and evaluation criteria for each phase, progressively expanding in size and scope. The first half of each semester is research-oriented, involving 3 short phases of work: material + fabrication experiments with plaster casting, resilient systems research, documentation + analysis, and the design of prototypical component and envelope systems. The second half of the semester is focused on building design + development, with the goal of developing a synthesis of a wider range of issues and criteria associated with the design of a more complex array of diverse site/program-related parts and wholes as resilient systems.

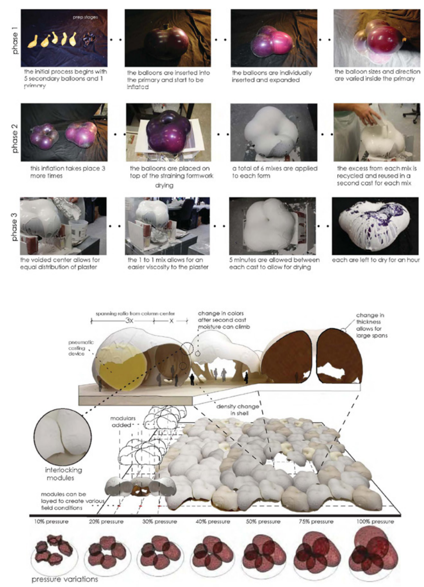

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Figure 2: Casting experiments, by Michael Signorile

MATERIAL PROCESS

The course’s exploration of precast concrete begins with a series of material-specific experiments to gain direct, ‘hands-on’ experience working with the casting process and to develop an understanding of concrete’s material properties and capacities as a “liquid stone”. Formed out of the alchemic interactions between liquid and solid matter, the plasticity of concrete as a latent material property and behavior is explored. Students test how seemingly solid and inert, end-objects are developed through fabrication processes that are changing, indeterminate, and responsive. The goal of this exercise is to develop both an intuitive sensibility and precise techniques for working with the dynamic nature of the casting process. Plaster is used as a proxy for concrete in this assignment to allow students to acquire basic skill at designing and making various mixes and molds and gain first-hand experience working with 4D design and fabrication processes. All of the final casts are cataloged and analyzed for the techniques used and effects produced. Students identify a fabrication method that is worth repeating, create an instruction set for how to do it, and then imagine a real application.

Upon completion of these casting exercises, the class conducts plant tours as an introduction to the precast industry, meeting with PCI members and touring their facilities. This “beyond the classroom” experience is intended to reorient the students’ previous craft-based, material explorations towards the study of industrialized production processes and products, building their knowledge of precast concrete industry standards, products, and processes and emerging, technologies and innovations. Field trips have included visits to leading manufacturers of architectural precast concrete products, such as Slaw Precast and Universal Concrete Products, where the students saw precast wall panels in various stages of production, and learned about the complex processes involved in translating design ideas into built reality, from panel customization and shop drawing production, to formwork fabrication, factory quality control measures, and shipping logistics. Field trips have also been made to learn about specialty products and cutting-edge prototypes. At Coreslab Structures, students learned about the use of fiber-reinforced ultra-high-performance concrete (UHPC) in an innovative curtainwall system prototype called "Liquidwall", while at Architectural Polymers, Inc., a leader and innovator in the concrete form fabrication industry, the group met with Marshall Walters, President and CEO, for a presentation on forward-thinking digital technologies and tour of his state-of-the-art manufacturing facilities, where they saw examples of Computer-Numerically-Controlled (CNC) fabrication, elastomeric form-liner molds, thin-brick inlay systems, and custom photo-engraved image transfer technologies.

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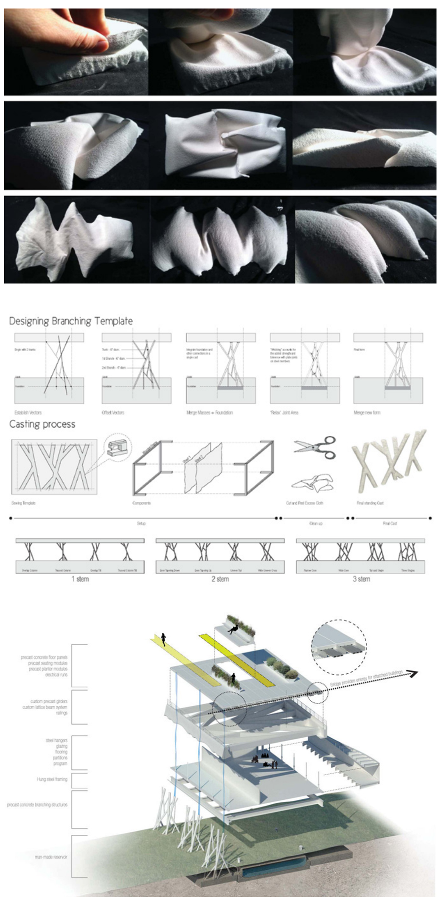


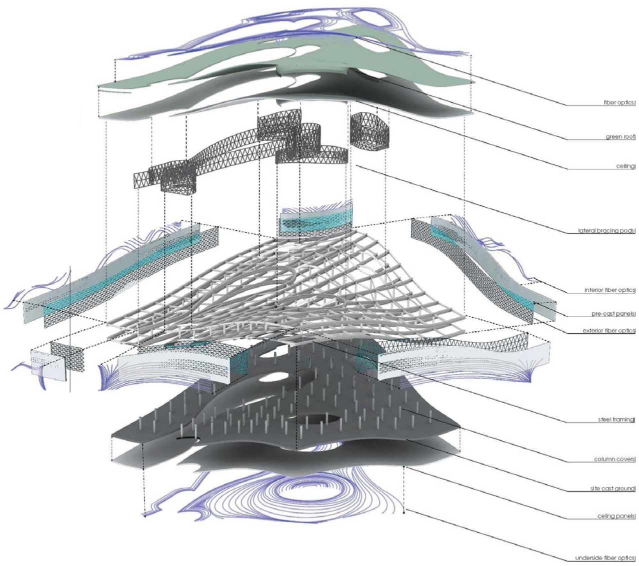
Figure 3: Component studies, by Gajun Lau

MASS CUSTOMIZED COMPONENTS

With this industry-specific knowledge of production capabilities, the next exercise focuses on the design of a repeatable building unit - a prototype with a range of possible physical variations and use applications. The exercise focuses specifically on the use of precast concrete in the design of custom architectural components. Such customization involves the design of a singular object as a multiple, to be distributed and organized into larger, more complex series. This includes the sizing and geometric configuration of building components, their multi-functional design, and coordination of these parts with whole building assemblies. Student knowledge-building occurs in-class with industry presentations by MAPA on the design of precast components and systems, and the provision of PCI resources that describe the standard catalog of components, their functional roles/types, and typical details. Component-based explorations of precast concrete aim to take advantage of its unique potentials in high-performance solutions by providing prototypical solutions that are easily customizable, variable, and adaptive. This alternative notion of prefabrication - commonly referred to as mass customization - addresses an old dichotomy of prototype design vs. user and site-specific design. With this contemporary evolution of industrialized production techniques, 'custom' solutions, rather than standardized, commercially available ones, are increasingly becoming a more viable option for designers, builders, and communities alike. This exercise focuses on the development of adaptable and durable building systems in terms of a particular area of precast concrete design - multi-functioning components (structural and envelope) - while working with economies of form, fabrication, and assembly.

HIGH PERFORMANCE BUILDING ENVELOPES

The next phase of work expands project scope from the design of a single prototypical precast concrete building component to larger, more complex assemblies within a specific building system typology and geography - the exterior envelope. Enclosure is a spatial act of both differentiation and connectivity that produces material configurations with an array of environmental and social effects. While performing different functional roles, at different scales, enclosures are often key points of interface within a building's organizational structure, and as such, are also a particularly concentrated area of design activity. A common example of this is the exterior envelope and its modulation between a building's interior and exterior. This traditional protective role of an enclosure acquires a greater significance in the context of the design of disaster-resilient communities, in which the physical edges of individual buildings have a more responsive and intricate



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relation to its (interior and exterior) adjacencies. As a site of spatial, social, and environmental exchange - one consisting of both constructed differentiation and connectivity - it is a complex whole in which these immaterial conditions and processes are primary considerations in its design. To this end, student work is focused on the rethinking of traditional enclosure typologies by using precast concrete systems. Repeatable and variable mass-customized solutions are developed in a highly creative and technically detailed manner, in response to specific enclosure-related performance criteria and tested as both generic prototypes and project-specific designs.

RESILIENT SYSTEMS

The final phase of semester work extends the initial development of a semi-prototypical design for a precast concrete building envelope and expands its scope to the design of an entire building, building complex, site/infrastructure design. With this up-scaled project scope and expanded set of complexities comes a shift of focus towards the mutual dependencies of these building' various parts and wholes, as an integral part of larger resilient systems. Here, the student work moves from the prototypical design of a single system type using precast concrete components, and its limited set of performance criteria, to a more wholistic and comprehensive building design that responds to its application in an expanded field of contextual considerations associated with its location and use. For each annual studio, a specific local municipality and building type is selected as a case study of how natural ecologies and urban geographies might perform as shared resilient systems, operating between water and land. Within this context, coastal building typologies - a waterfront marina, ferry terminal, disaster recovery center - are used as vehicles to research, develop, and test new synergies between precast concrete systems and resilience. For each project type, a different coastal risk type is identified as the basis for a resilient design scenario. Examples include the transformation of a bayside marina into a new public, mixed-use center for a community devastated by Sandy, the stabilization and upgrade to National Park facilities located on a highly exposed barrier peninsula, and in-land flooding affecting the redevelopment of an urban center.

Figure 4: Building Systems, by Edward Perez

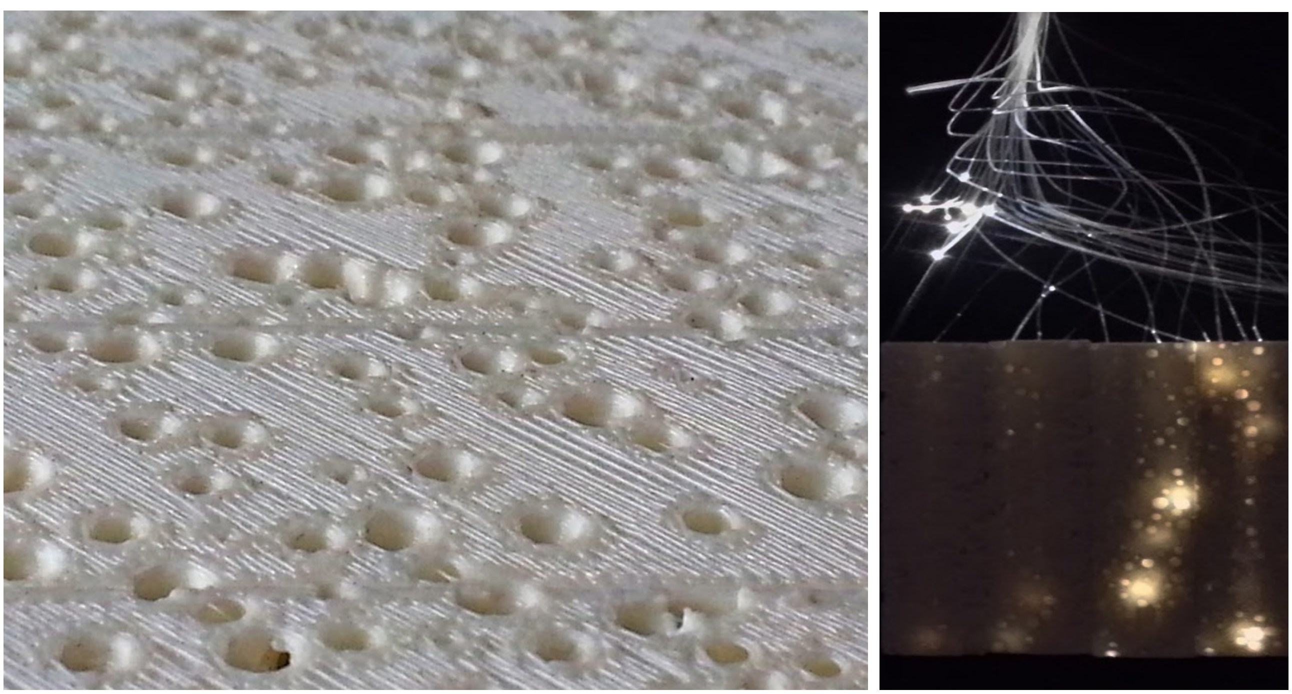
Student explorations focus on the development of newurban building typologies and building systems that aim to address a key problematic of all coastal development - that more people living close to the water, means higher risk.

DESIGN AS RESEARCH: STORM RESILIENT DESIGN WITH PRECAST CONCRETE

In the design studio, the technical development of projects is often limited by the broad project scope required by curricular structure and pedagogical objectives. To address this constraint, at the end of each semester, outstanding students from the studio are given the opportunity to conduct advanced work, as independent research work, supported by the funding from PCI. For its innovative use of precast concrete in a resilient design building solution, a student project from last year's studio was awarded First Prize in the 2014 Dana Knox Student Research Showcase. This event is a university-wide competition featuring the best of NJIT student research projects each year, nominated by the entire faculty. Projects from various academic disciplines, including engineering, biology, physics, and material science, are presented in an exhibition to industry professionals, academic community, and the general public. It celebrates the unique role of students within the university research community and showcases their work as the innovations of tomorrow.

This award-winning project is by Edward Perez, a student at the top of the class who also presented his work at the 2013 PCI Convention, and was subsequently continued to develop his project as independent design research with Matt Burgermaster, the PCI Studio program coordinator. Titled *"Porosity + Luminosity: A Storm-Resilient Precast Concrete Wall System Featuring Integrated Fiber-optic Lighting"*, the project is a design prototype for a high-performance exterior envelope system that combines light-weight/high-strength precast concrete wall panels with integrated fiber optic strands to create a light-emissive, yet highly durable "porous" building façade. This resilient building system is envisioned as a prototypical public "way-finding" and back-up lighting system for emergency

Figure 5: Prototype, by Edward Perez



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uses in disaster-prone communities. The project is envisioned as a demonstration of the design of resilient building systems with precast concrete, as well as a model for future resilient building types that may stand to benefit from their use.

The first phase of research was aimed at creating a foamed concrete. Unique fabrication techniques were developed using plaster casting methods that incorporate the material's porous qualities into a material that is traditionally solid and heavy. This exploration began by introducing air bubbles into the plaster mix as it dried, as well as using pressured C02 to inject air bubbles into the mix, while cooling it down to rapidly dry it. External conditions such as passing air currents and sudden movements were found to interrupt the drying process. Due to this, the plaster mix was placed to dry in an air tight container to achieve the best results. Various mix additives, such as a combination of different cooking oils and water shaken together and various types of liquid soaps where incorporated in an attempt to reach a more porous mixture. There were 20 test casts poured before a final desired effect and method to achieve this effect was reached. The final mix design incorporated 2 parts water, 1 part plaster, and 1 part soap that were whisked to agitate and create a dense amount of air bubbles in the mixture. The final "porosity" type selected for further development as a prototypical building component was the one that minimized material weight and density, while maximizing light emissivity.

In the second phase of research, the scope of this material exploration was expanded to test the most effective way to transmit both natural and artificial light through the inner core of a 'porous panel' prototype. This testing focused on the design of a single, repeatable building component. Incorporation of fiber optic strands specifically placed allowed the material to glow as pre-determined by their placement in during the casting process. A wide range of pattern options were tested and their effects cataloged. Strands with a diameter of .75mm were placed approximately .25" from the surface of the material as a series of arcs fanning away from a central pivot point offset from 1 - 2". The amount of light emitted by the fiber optics and the lighting effects created by them was determined by controlling the porosity of the material, and the placement and direction of the fiber optic strands on the final prototype panel of a size of 3" x 7".

In the third phase of research, the component prototype was developed as an enclosure system, for use in the design of a disaster response center (DRC), located in Long Branch, New Jersey. This is a public building, centrally located on a prominent site between the ocean waterfront and downtown core. The 2-story structure features a unique integration with its adjacent landscape that provides access to an occupiable rooftop with remarkable views to the ocean, and able to act as an area of refuge in the event of emergency. The building's exterior wall panels use fiber reinforced ultra-high performance concrete (UHPC) and were designed to a maximum size of 13'-0" x 25'-0" as an 8" thick insulated panel composed of (2) 2" double wythe and 4" insulation held together with fiberglass ties. The fiber optics strands are located on the exterior faces of the panel porous concrete. The fiber optics embedded in the porous concrete wall system would connected to a lighting control system, able to be programmed by the DRC operations center of the first response center to respond to a wide range of events – from natural disaster to community events. Various color schemes and lighting patterns would be assigned to each event, allowing the building to transform its exterior walls into a super-sized public information board. In everyday, non-event situations during the year, the building's lighting effects would animate the cityscape, helping to contribute to its ongoing efforts at urban revitalization, while also serving as a beacon for the community during emergency situations.

This particular design research project not only demonstrates the exemplary efforts of an individual student enrolled in the PCI design studio, but also the value of an integrated education and research experience, created through industry support and collaboration, in the advancement of new approaches to design and construction practices aimed at addressing contemporary challenges affecting everyone. The work of the PCI Architectural Design Studio at New Jersey Institute of Technology is an example of an academic architecture program that couples specific knowledge from industry with general knowledge in the expanding field of resilience. The studio's work was aimed at creating more multi-valent and productive synergies between precast concrete construction solutions and the broader field of considerations associated with the complex problem of designing projects located within coastal community with a high vulnerability to storm hazards - a problem whose breadth extends well beyond the solution space of a single material type (precast concrete), as well as a single discipline (architecture).

ENDNOTES

1. Ota, Hiroshi, "When the World Floats", Matter in the Floating World, New York, NY: Princeton Architectural Press, 2011.

2. Braham W, and Moe K, "Performative Practices: Architecture and Engineering in the 21st Century", 2011 ACSA Teacher's Seminar, Washington, DC: Association of Collegiate Schools of Architecture (ACSA), 2011.

3. D'Arcy, Tom, "Chairman's Message", PCI Foundation, Industry Vision, Issue 6, Fall 2013.