


Structures for Relief & Resiliency: Enhancing Creative Applications of Technical Acumen through Constrained Conditions

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Pairing Building Technology with Humanitarian Design Efforts

Every year, tens of millions of people worldwide are displaced or otherwise harmed by natural disasters, warfare, and economic / social inequities—an even larger number suffer from oppressive conditions that also require humanitarian assistance. Relief operations rely heavily upon the availability and usefulness of places, objects, and experiential operations used to help them provide provisions for food, water, and shelter.

And yet, despite nearly a century of historical precedents and technology-centric design philosophies aimed at addressing humanitarian issues through design, integrated design solutions still remain largely marginalized or omitted from these practices. In fact, the operational manuals developed by the most predominant relief agencies and non-governmental organizations (NGOs), have included very little, if any, information about the *actual* design dimensions, materials, or deployment strategies.¹ These efforts are incomplete without design.

These unfortunate omissions suggest an important opportunity to engage real-world humanitarian design efforts with practical efforts and educational activities. This paper will argue that the constrained conditions related to disaster relief and resiliency are, in fact, ideal topics for building technology educators and students—and that integrating these efforts into course activities is highly beneficial to student learning. Technical acumen is an inherent part of all phases of work particularly because

of the expectations of elevated material utilization, a synergistic connection between products and production, and a necessary portability / deploy-ability of the designs. The work has inherent evaluative standards for performance assessment as well—both functionally and technically—that go beyond a judgement of ‘right or wrong’ solutions.

Unfortunately, the multi-faceted nature of disaster relief and resiliency problems often excludes this work from traditional architecture design studios and/or building technology courses. Or worse, sometimes these complex topics are marginalized into a search for “better” shelters for the sake of pedagogical simplicity. Effectively conveying these learning objectives requires changes in traditional building technology activities, participants, and assessment criteria.

This paper will discuss three exemplary projects that were designed and prototyped by interdisciplinary teams of senior and graduate Architecture, Landscape Architecture, and Interior Design students in the *Structures in Service: Design for Relief and Resiliency* design studio at Iowa State University’s Department of Architecture. The projects include: A portable storage container that doubles as an elevated beam/slab floor system for relief tents, a shell that uses a modified ferrocemento solution to enclose a well-water system while integrating physical spaces for social activities, and a “brick” made from recycled tires that is retro-fit into

existing masonry houses in Mexico to increase resiliency to seismic forces.

The work was completed in a design studio which included an explicit emphasis in building technology principles of design and production, and the haptic-learning opportunities of design-build activities. The groups researched real-world ongoing relief and rebuilding efforts that would benefit from a critical integration of structural and materials design principles—including the design of objects or operations. The “build back better” ethical framework and categories of care adopted by the relief organization suggest a more thorough assessment of use and re-use, so full-scale prototypes were constructed and tested as part of the design process (Figure 1).



Fig. 1. Constructing fiberglass bin for Store Floor design, 2017

The Role of Design-Based Research

The first step in developing this coursework was to create a learning environment in which students assume the role of design-researcher. Researchers play an important role in supporting real-world humanitarian efforts. Relief and recovery efforts are so complex and multi-faceted, that organizations such as the United Nations (UNHCR &

UNISDR), and various NGOs rely, to an extent, on an open-source approach to accepting research from outside sources. By policy, before operations are implemented in the field, these practices are initially researched, tested, and evaluated—eventually becoming position papers or policies.² In support of these efforts, researchers produce topic-specific position papers based on their expertise and pursuing funding to help develop and test their work. This process can be translated to design efforts.

Designing for disaster relief, recovery, or resiliency is another form of applied research. As such it requires a foundational hypothesis, an ideology that guides the work, a design methodology that incorporates the particular tools and materials proposed for the design and production, and an evaluative process of prototyping including deployment and use.

In the initial stage of design-research, students study various design philosophies and ethical practice models for humanitarian design. This design research is commonly situated within the broader questions of modern design; specifically the question of how technological innovations can be leveraged to assist in humanitarian efforts through the design and production of constructed environments.

Foundational Design Philosophies

In the 1938 book *Nine Chains to the Moon*, Buckminster Fuller (1895-1983) outlined a philosophy of industrialization that concluded with the belief that humankind could actively evolve by transforming our patterns of “making” to create more possible efficiencies by harnessing our available technology. He coined the term “*ephemeralization*” to describe a philosophy of design and systems operation that sought to do “more and more with less and less.”³ Fuller would evaluate the proportional weight of an object because he believed a lightweight structure reflected an efficient combination of materials and forms.

The applications for this philosophy weren't limited to disaster relief or rebuilding efforts but were an important part of this type of work. The performance objectives for objects and spaces utilized for humanitarian relief—lightweight, efficient, portable, innovative, etc.—all aligned well with this ideology. His eventual development of geodesic domes and a joint system that allowed for rapid deployment were widely implemented in operations for relief agencies and military operations.

The German engineer, builder, and Pritzker Prize winning designer Frei Otto (1925-2015) spent a great deal of his career developing designs for humanitarian purposes. Like Fuller, Otto believed that the inherent efficiency of innovative materials and lightweight structural forms could help solve difficult problems in disaster relief or rebuilding scenarios. He described his philosophy as search for a broader view about the purpose of design—something that went beyond “buildings.” Otto’s particular focus was the development of, as he described, “Structures with a minimum of material and time related to economy and energy.”⁴ Specifically, he believed that designing with tensile structures (tents, membranes, and pneumatics) would provide the ability to create highly portable and rapidly deployable structures (Figure 2).

Relief tents are now ubiquitous, but Otto saw the potential for tensile structures to solve greater problems than simply shelter. For the last decades of his career, Otto developed and engineered a myriad of tension-membraned objects including: floating cities for food production, suspended water cisterns in remote areas, and rapidly deployed pneumatic dams for flood prevention. Surprisingly, despite the thoroughness of his engineering work, few of these proposals were ever widely implemented.

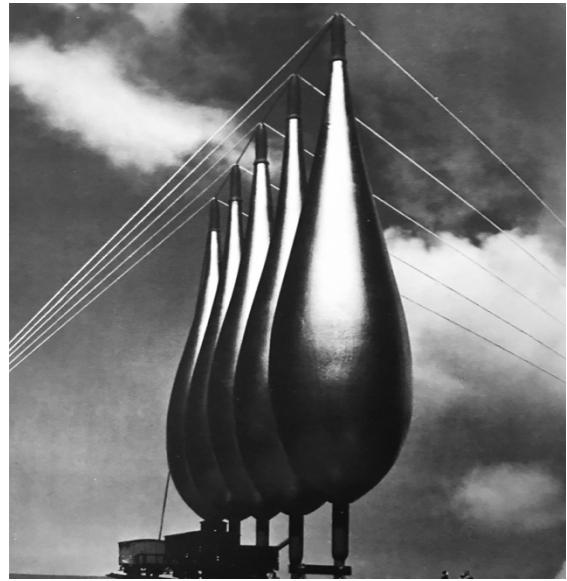


Fig. 2. Water cistern “bladder” design proposal, Frei Otto, 1956.

Victor Papanek (1927-1998) was contemporary of Fuller and Otto, who focused on post WWII-era industrial design objects created for humanitarian efforts. In *Design for the Real World*, he argued for a social-consciousness design ethic that including users/participants in the design process—particularly groups that had been traditionally marginalized.⁵ Papanek saw design as a tool for social good and political change and spent a great deal of his career working in developing countries. He had less faith than Fuller and Otto on the role of contemporary technological innovations (called them tools for “techno-ideological paymasters”). He often looked at vernacular methods, or “local solutions to local problems” instead. His design philosophies and probing ethical questions established him as a predominant voice in humanitarian design efforts in the 1960-70s.

Conspicuous Absence of Design

Despite the compelling proposals put forth by Fuller, Otto, Papanek, and others, the larger focus of designers in the 1950-70s was the design for spaces that could survive or mitigate the impact of atomic war, not the broader humanitarian crises of food and water shortages or refugees.⁶ During this same era, influential bureaucracies

of humanitarian care emerged and evolved (e.g., United Nations, U.S. Federal Emergency Management Agency (FEMA) etc.) and their adopted design philosophies shifted as well.

Instead of embracing a human-centric design focus for innovative technical solutions, most agencies and organizations opted for consistency and uniformity. This is understandable as it relates to policies of care, but it was detrimental to the integration of specific design efforts. One type of design solution shouldn't be "universal" or interchangeable with all others. The functional failures of the standard UNHCR relief tents and FEMA trailers are evidence of the consequences.⁷

During this era, the balance of design-based research and development for objects and spaces used for humanitarian efforts (shelters, food, water, infrastructure, etc.) shifted towards military industries and private and/or non-profit researchers. The practice of technology transfer between entrepreneurial designers, researchers and the military thrived, particularly as global defense budget funding increased rapidly in the 1980s. Unfortunately, many of these innovations weren't widely applied to relief activities because military interventions in international relief efforts are often met with skepticism and distrust by communities in need. Frankly, relief agencies didn't have the same type of access to funding for research and development as they channeled their money towards operations.

This gulf between design-research and humanitarian relief operations has only increased over the last several decades. Its absence has even become codified. For example, the operation and training manuals developed and adopted by a large consortium of renowned NGOs, including *The Sphere Project* and the *Good Enough Guide* don't include *any* design drawings or diagrams.⁸ These manuals discuss operational guidelines for managing water, shelter, food, healthcare, and education in great detail—all aspects of daily life that have

predominantly shaped the design of our physical environments—yet the associated design considerations remain absent from policies of care.

Not including explicit design content is understandable to a certain extent. These NGOs don't produce design solutions themselves and don't have funding for research and development. They rely on technology transfer from military applications, and / or the ingenuity of researchers and developers to create available products through an entrepreneurial system or a shared open-source research program.

This entrepreneurial system of research and development has negative consequences on the types of design environments integrated into the field operations. Specifically, because the development and production is market-based, it is inherently biased towards the most affordable and widely available solutions. UNHCR tents aren't used because they are the possible best relief shelter, but they meet the margins of the lowest-acceptable denominator of the agencies cost-benefit analysis (Figure 3).



Fig. 3. UNHCR Tents provide marginal qualities of shelter

By failing to integrate design considerations into their operations, the spaces and products are treated as either interchangeable or inconsequential. This is a difficult lesson for students to learn; particularly when they realize that the “quality” of their design won’t solve the larger problems. This lamentation can be shifted towards other opportunities by accepting the entrepreneurial model of design development and finding other entities that support, fund, and implement good design work.

Defining the Problem by Embracing Constraints

Design work can be implemented into relief and resiliency efforts without relying on operational manuals. Professional volunteer organizations (e.g., Engineers without Borders), privately funded philanthropic foundations (e.g., Rockefeller Foundation), non-profit architectural design consortiums (e.g., the former Architecture for Humanity), and design-oriented governmental organizations all make significant contributions to world-wide problems and each participates in creating (or funding) design. Instead of relying upon one entity for funding, development, research, and implementation students discover that a broader network is needed.

Learning how to develop a design proposal that appeals to a larger group is challenging. Student work left unchecked tends to either aim too broadly (e.g., “our goal is to end world hunger”) or to believe that an empathetic approach to design (like Architecture for Humanity’s motto “Design Like You Give a Damn”) is sufficient. Constraints are useful.

Students are asked to see their work not as an independent inquiry, but as an extension of an ongoing “conversation” and/or design efforts related to food, water, education, health-care, power, and even economic and social issues. They identify real-world efforts in research, practice, or field operations where additional design attention could improve the resiliency of

environments, or improve reconstruction, or assist in relief efforts. Teams are encouraged to add others to their design team including other instructors, researchers, fabricators, or corporate sponsors.

The most difficult portion of establishing a scope of work is being both realistic and aspirational about the desired impact of the proposal.

Evaluation Challenges and Incremental Improvement

How should performance or impact be measured? Giving someone a safe and secure water source who previously didn’t have easy access to one is certainly an improvement. But this “have or have not” method of evaluation doesn’t distinguish the relative value of a solution compared to other options. What makes a particular design “better” than others?

Groups who do this work in real-world practice tend to favor a performance-based design ideology—one that seeks incremental improvements (e.g., a well that pumps water faster, or a tent material that is more durable, etc.). The viewpoint is so predominant that the United Nations International Strategy for Disaster Reduction (UNISDR) thematically named a resolution for their rebuilding policy, “Build Back Better” to reinforce the idea of steady improvements in recovery and reconstruction.⁸

This engineering-based approach emphasizes the practical manifestation of a solution (e.g., “building a well”) over the broader inquiry (e.g., “what are the larger issues related to water safety, security, and community space?”). Tim Brown of IDEO distinguishes this by classifying the problem being solved as either a “noun or a verb;” by focusing on a noun (e.g., “water well”) the work is locked into a mindset or incremental betterment. But when the problem is treated as a verb (e.g. “water collecting”) it can be seen in “...all of its wicked complexity.”⁹ Because academic course-work has the freedom of initial design inquiry, students are encouraged to see the problems as “verbs.”

Prototyping: Structures, Materials, and Operations

Most of the course activities are based on real-world examples of research, design methods, and evaluation standards, so it may be implied that the work produced is intended to be implemented immediately into field operations. It isn't. One might assume that doing so would help one to see if the solution “works” or not, but this could be more harmful than beneficial. Student aren't field-operators, they are researchers. Designers are not trained for field work, academic calendars are too constricted, and short-term engagements with communities are proven to be more harmful than beneficial. Communities in need aren't lab subjects.

But like any research question, the work *must* be assessed. It is important to develop other ways to test the work and improve it. One approach is to embed a performance-based criteria in the work (e.g., an outdoor classroom shelter that can be folded and unfolded when needed)—either that process works or it doesn't. Technical acumen is an inherent part of all phases of the work particularly because of the expectations of elevated material utilization, a synergistic connection between products and production, and a necessary portability / deploy-ability of the designs.

The relative success of the work can be assessed, at least from a technical perspective, by emphasizing the importance of integrating and refining structural and material performance standards. This degree of assessment also requires more work than just drawings.

In order to demonstrate the critical lessons of material utilization, fabrication limits, portability, affordability, and integration with operations, each group is required to build a *full-scale prototype*. Building prototypes has two critical pedagogical benefits: it immediately engages students with haptic-learning methods of “making and breaking” and it allows them to see the limits of how contemporary design and production tools can be

leveraged in support of these efforts. Students seek out external funding sources to under-write the expenses and find partners with local fabricators for more difficult construction proposals (Figure 4).

The final prototypes are all intended to be portable—as they would be in real-world scenarios. Therefore they are constructed in one location and installed temporarily in other locations for reviews and exhibitions. This process embeds the lessons of material efficiency (Fuller's valuation of “lighter” structures), challenges them to develop deployment strategies, and reveals the difficulty of creating buildings and objects that must “perform” a function.

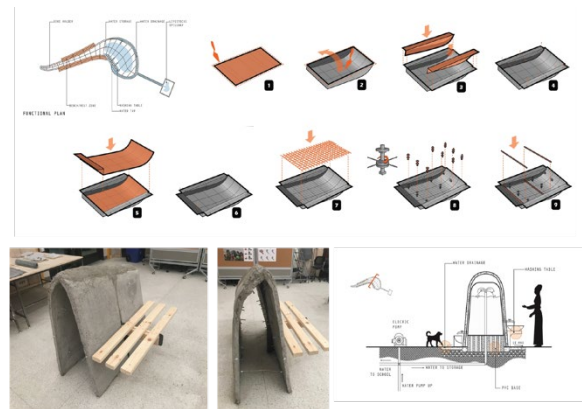


Fig. 4. Digital tools used to translate complicated forms into an accurate construction manual for prototyping the Waterwall proposal, 2018.

Project Examples: Design for Relief and Resiliency

The following projects demonstrate the breadth of possible project designs, the value of linking the design-based research to building technology, and the continued learning opportunities revealed through a design-build process. Each project description will include a brief description of the problem being addressed, a description of the proposed solution, the specific structural or material issues addressed, and a summary of the evaluation process.

Like other compelling research projects, the development of the projects weren't intended to end at the course's conclusion. All three of the projects discussed are still in a particular state of continued development, even though the studios finished long ago. Two of the projects are undergoing the initial stages of review for potential patents (Store Floor and Retro-Brick) and the construction process of the third project (Waterwall) is being further developed by the author as part of a sponsored Wells Concrete Construction Research fellowship (Figure 5).

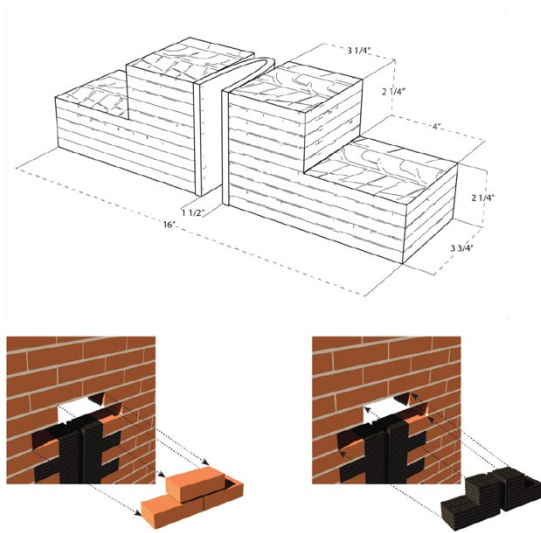


Fig. 5. Drawing submitted for patent review, Retro-Brick proposal, 2018.

Project 1: Store Floor Elevated Slab and Storage

Instead of trying to design a better emergency shelter enclosure than tents, this group designed a system that could improve the quality of life *within* the tents by focusing on the ground/floor. In their research they discovered that nearly 4 million people live in tents worldwide—many for years longer than the intended 6-month lifespan. To remain portable and affordable, tent systems only include the membrane and supports. Although they shelter from the sun, wind, and rain, these tents do not include any floor system—inhabitants rest on

the ground. Living on the bare earth causes higher risk for parasitic infection, anemia, diarrhea, lower development rates, suicide and depression, flash flooding risks and hypothermia.

Although most inhabitants rest directly on a membrane spread on the ground, some tents use rubber tiles laid atop wooden pallets. Neither solution can accommodate for a variety of scenarios including rocky, uneven ground, sloped terrain, and/or flash flooding. Functionally, the membranes are also a problem because the tents aren't secure environments so issues of food and water security, and personal safety are at risk. The average refugee spends 16-20 hours a day in this environment so the problems are profound.

Their solution, named Store Floor, was designed to provide a solution for both secure storage and human comfort and health by creating an elevated floor system that doubles as a storage space within the floor itself. It was designed to be a modular system that is adaptable to UNHCR tent sizes that could be easy to assemble by the tent inhabitants. The bins are fabricated out of recycled structural plastic; they rest on a perimeter support frame made of aluminum. Each bin is capped with somewhat flexible plastic lids to safely storage personal belongings and provide a comfortable surface for seating and sleeping.

The floor bins had to solve difficult structural and material problems. For issues of portability and assembly, the floor system needed to be somewhat deep, hollow, lightweight, stiff, yet strong enough to span between the adjustable supports on the perimeter—a paradoxical challenge. To achieve the structural criteria of a spanning system, the cross-sectional geometry of the Store Floor looked at a single-pan formwork used in pouring structural slabs and modified the profile to optimize function. The dimensions were developed in collaboration with a local structural engineer. (Figure 6).

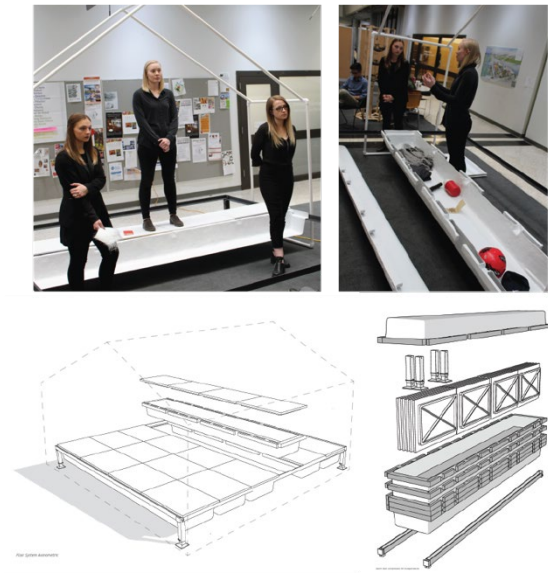


Fig. 6. Store Floor proposal and prototype, 2017.

For testing, the students re-enacted the entire process of receiving, unpacking, and assembling the system. They built two full-length bins by creating a fiberglass shell over a digitally fabricated formwork (a concession of time and expense that different from their actual design). The perimeter frame was built by a local steel fabricator who helped the students design the details that helped it fold, like a bed-frame, and snap into the four adjustable legs. They all stood on the bins at the same time and invited all four reviewers to do the same to demonstrate the strength, stability, and stiffness of their proposal.

Project 2: Waterwall Community Water Station Shell

This group framed their problem—water access, safety, and security—not as an issue related to emergency relief operations, but as a fundamental humanitarian issue. Their design work started at the conclusion of a meeting they attended for the Engineers Without Borders student group. The group described a well they had just recently completed in Ullo, Ghana and shared photos of the project. The well was useful, but the photos showing how it was being used were disappointing. Despite a great deal of engineering “design work” there was only a pump handle sticking up from the ground—no accommodations

for any of the myriad functional and social interactions that occur at such important community locations. They imagined a scenario of how the project could be changed if they would have worked as design collaborators with the Engineers Without Borders.

They immediately set constraints to limit their “what-if” options: They’d include a cistern into their proposal for functional reasons (it reduces time to access water) but the cistern would need to be properly secured so it couldn’t be easily vandalized or stolen. They determined that they’d only use the same scope of tools and construction materials that were already used to construct the well. They wanted to create a water station that accommodated a broad range of functions such as: sitting, bike storage, water container storage, dish washing station, and run-off tray for watering livestock. To solve this problem, they decided to use digital design tools to create a double-curved shell enclosure that could enclose the cistern and provide a variety of curved surfaces for the functions (Figure 7).



Fig. 7. Rendering of Waterwall proposal, 2018.

They recognized that the biggest problem with their proposal is the complicated nature of the constructed form and the heavy mass of the shell structure. As a solution, they created a modified “ferro-cemento” system for the shell that could be assembled and post-tensioned from several individual pieces. They developed a system for casting the shell pieces on the soil spoils from the well drilling; to achieve the double-curvature of each piece

they developed a low-tech three dimensional grid system of measurement and specific fabric “pattern” that would fit in a properly formed hole.

They created a design manual with step-by-step instructions for construction, cut out a variety of membranes derived from their curved form, and built a free-standing six foot long portion of the shell from four separate curved pieces that were cast using the construction system they developed. A bench was integrated into the shell. The additional ongoing work seeks to clarify this process of form-finding and construction, ideally using feedback from local contractors and implementing a natural fiber reinforcing.

Project 3: Retro-Brick: Enhanced Seismic Resistance with Recycled Materials

Six months before the studio began, 228 people were killed in the earthquakes in Mexico City and the surrounding areas. 44 buildings collapsed and 1,800 other were greatly damaged. This group all had personal ties to Mexico and wondered if there was something that could be done. They researched traditional solutions to make buildings more resilient to earthquakes and realized that many of the recommendations (more rebar, stiffer concrete frames) weren’t practical for the economic and construction conditions of housing in Mexico and did little to address existing buildings.

Their goal was to develop a building system that could be retrofit into existing masonry structures in Mexico to make them more absorptive of seismic forces. One of their primary goals was to make this system something that could be installed without special tools or expertise. Ideally it would be easily available and relatively affordable too. The solution was to create an expansion joint system to absorb the seismic energy so they needed a flexible building material. They found their solution in a scrap heap of tires. Mexico collects 40 million tons of scrap tires a year, recycling only 12% of them. Because

tire rubber is strong, yet ductile, it is an ideal material to act as a brick with an expansion joint.

They created new “bricks” by laminated layers of recycled tire rubber together. Through a testing process on a full-scale brick wall prototype they built, they realized that a vertical course of bricks alone wouldn’t be absorptive enough so they created two bricks and connected them with a single layer of rubber that would act as an expansion joint between the two bricks. In the process of retro-fitting this new system within an existing wall, they eventually created a Retro-brick that was two courses high with a vertical joint between. Starting at the bottom, they’d remove two bricks and a single brick centered above (running bond) and all mortar and then install and shim in place the new rubber brick. This process of removing and replacing the brick took only 5 minutes (Figure 8).

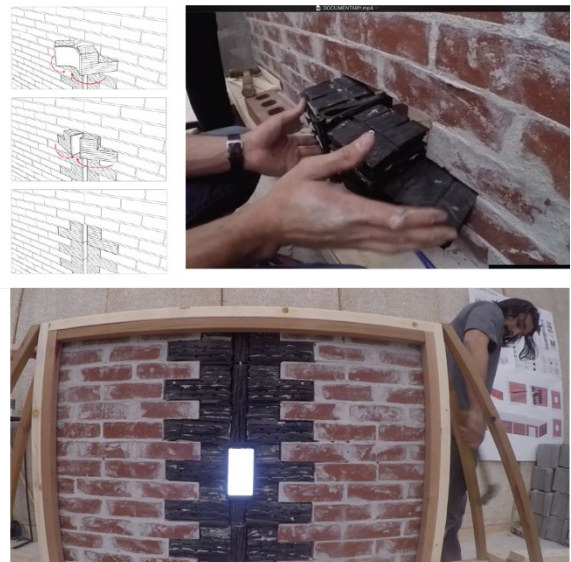


Fig. 8. Testing of Retro-Brick installation and vibration dampening, 2018.

Testing the effectiveness of the application was difficult—seismic evaluation always is—but there isn’t one particular arrangement of existing housing in Mexico so there was no guarantee that this system would be sufficient. They settled on evaluating the design’s seismic

performance in relative terms to see if it would absorb energy in a basic vertical wall applications. Digital simulations weren't effective, so they consulted with a civil engineering researcher to determine an initial physical testing method. They applied a lateral force by hitting one side of their wall with a mallet and measured the dissipation of horizontal forces on the opposite side of the Retro-brick. Using a vibration measuring application on their phones they recorded results which showed a dramatic decrease in the force transfer. The data wasn't accurate enough to run calculations, but as a proof-of-concept test, it succeeded.

Reflection, Critiques, and Lessons Learned

Because these problems are vexing and multi-faceted, it is difficult to assess the overall success of the proposed solutions from a functional and operational point of view. There are many potential solutions that could provide incremental improvements and the studio limits don't allow for proper evaluation and redesign.

This process of how the course was set-up should be subjected to the same critiques that are often leveled at similar work. For example, it is important to reflect on any inherent biases held by the designers and the systems that support this work. This is particularly true because the work was prepared "outside" of the context of where it would be applied. Additionally, the work was completed with very little, if any, contact or collaboration with

agencies that do this work—one of the constraints of a semester's time-line.

There is a risk that producing this work would be perceived as an expression of colonialism or that it oversimplifies more complex economic, social, and cultural factors that have contributed to the problems. To an extent this is a fair concern, but it isn't the intent of the course activities. These concerns were intended to be mitigated by anchoring the research topics and potential projects towards on-going efforts, and learning from the work that was already started by others. One way to address this problem is to realize that this work need not be made exclusively for "others" in far-away places. There are design issues related to relief, recovery, and resiliency in shelter, food, water, etc. in many communities—including nearby locations.

Overall the course activities successfully provided a forum for design-based research that effectively addressed various problems found in relief and recovery methods. The focus on critically integrating building technology topics from the initial design thinking, to the haptic-learning methods of development, and through a set of evaluation protocols, provided opportunities for increased learning about topics not normally accessible from studios or technology classes. The student work addressed difficult problems in a way that demonstrated a high level of technical acumen related to structural and material technologies.

Notes:

1 Ed. Red Cross, Red Crescent, NGOs. "The Sphere Project: Humanitarian Charter and Minimum Standards in Humanitarian Response" Practical Action Publishing: United Kingdom. 2014.

2 Neder, Federico. "Fuller Houses, R. Buckminster Fuller's Dymaxion Dwelling and other Domestic Adventures." Lars Muller. 2008.

3 Ed. Otto, Frei. "Tensile Structures: Design, Structure, and Calculation of Buildings of Cables, Nets, and Membranes." MIT Press. Cambridge. 1962.

4 Papanek, Victor. "Design for the Real World: Human Ecology and Social Change." Chicago Review Press. 1984.

5 Severud, Fred. "The Bomb, Survival, and You." Reinhold Publishing Corporation. 1955.

6 Lee, M., Weil, F., & Shihadeh, E. "The FEMA Trailer Parks: Negative Perceptions and the Social Structure of Avoidance." *Sociological Spectrum Journal*. Vol. 27, Issue 6. 2007.

7 Emergency Capacity Building Project (ECB). "The Good Enough Guide: Impact Measurement and Accountability in Emergencies" Oxfam Publications: Oxford. 2007.

8 Ramirez, Ernesto Ottone, "Culture in city reconstruction and recovery: Position Paper." World Bank, UNESCO. New York. 2018.

9 Brown, T. & Katz, B. "How Great Design Can Fix the World's 'Wicked Problems'." *Fortune Magazine*. February 2019.

10 Whitehead, Rob. "Supporting Students Structurally: Engaging Architectural Students in Structurally Oriented Haptic Learning Exercises." *Architectural Engineering Institute Proceedings*. American Society of Civil Engineers (ACSE). Penn State University. April 2013.