INNOVATIVE HOUSING SOLUTIONS FOR POST-QUAKE HAITI

PROBLEM: Haitian families have still no viable roadmap to enable reconstruction of resilient homes in the wake of the 2010 Earthquake, as their traditional masonry construction has proven too expensive to safely re-implement, leaving them indefinitely confined to transitory shelters.

SOLUTION: Formulate an integrated process that empowers Haitian entrepreneurs to deliver affordable, dignified, engineered housing within the local informal economy through innovative housing systems that navigate engineering and non-engineering constraints.


Design iteration with local engineers (Haiti)


Discussing housing concept (Haiti)


Cage Fabrication (US)


Cage Fabrication (Haiti)


Panel Casting (US)


Panel Casting (Haiti)


Formwork Erection (US)

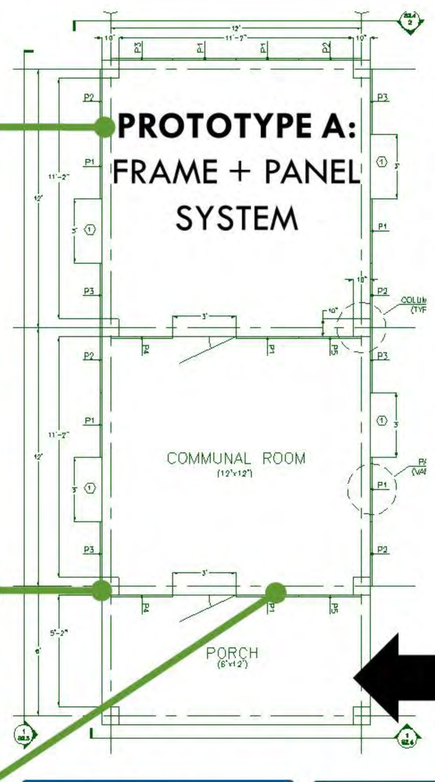

Formwork Erection (Haiti)

INNOVATION EXCHANGE: US OPS (R & D + Structural Prototyping) ⇔ HAITI OPS (Feasibility/Constructability + Finishes)

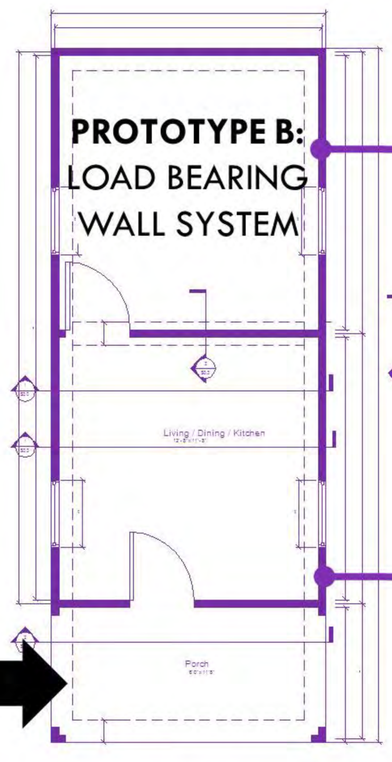

Placing Reinforcement

Reinforcement Preparation


Panel Installation



EXPO OBJECTIVE: Through partnerships between faculty, undergraduate students, licensed engineers, allied construction professionals, **and their Haitian counterparts,** vet the constructability, feasibility and scalability of two reinforced concrete housing typologies for post-quake Haiti using **full-scale prototypes.**




Rebar Placement


Formwork Erection


Panel R+D


Panel Mix Design


Fabrication


Rebar Inspection


Prototypes Under Construction (Webcam)

PROJECT PHASES: CONCEPTUAL DESIGN → **CONCEPT REFINEMENT** → **MATERIAL TESTING** → STRUCTURAL DESIGN → STRUCTURAL DRAWINGS → **FABRICATION** → **CONSTRUCTION SEQUENCING** → SITE PLANNING → PERMITTING → BUDGETING → PROCUREMENT → PROJECT MANAGEMENT → **CONSTRUCTION**

DISCIPLINES: Civil Engineering: Structural ● Civil Engineering: Materials ● Civil Engineering: Geotechnical ● Civil Engineering: Construction Management ● Mechanical Engineering ● Electrical Engineering ● Architecture ● Political Science ● Development Studies ● Liberal Studies ● Marketing ● Social Entrepreneurship

ABSTRACT: [redacted] Innovative Housing Solutions for Post-Quake Haiti

Haitian families still have no viable roadmap to enable reconstruction of resilient homes in the wake of the 2010 Earthquake, as their traditional masonry construction has proven too expensive to safely re-implement, leaving them indefinitely confined to transitory shelters. As such a team of faculty and students have been working, for the last four years, to formulate an integrated process that empowers Haitian entrepreneurs to deliver affordable, dignified, engineered housing within the local informal economy through innovative housing systems that navigate engineering and non-engineering constraints. To realize such a design, **multi-disciplinary participation** between students and advisors from wide ranging fields was necessary. These included four sub-disciplines of Civil Engineering, Mechanical Engineering, Electrical Engineering, Architecture, Political Science, International Development Studies, Liberal Studies, Business (Marketing), and Social Entrepreneurship; however, in order to bring their conceptual design into reality to meet the needs of displaced families in Haiti anxiously waiting its arrival, an ambitious semester-long project (**The Expo**) was executed in the Spring of 2014, with following objective:

> Through partnerships between faculty, undergraduate students, licensed engineers, allied construction professionals, and their Haitian counterparts, vet the constructability, feasibility and scalability of two reinforced concrete housing typologies for post-quake Haiti using full-scale prototypes.

The Expo allowed students to directly experience the **entire project life-cycle**, including critical phases of: Conceptual Design, Concept Refinement, Material Testing, Code-Compliant Design, Structural Drawings, Fabrication, Construction Sequencing, Site Planning Permitting, Budgeting/ Quantity Estimation, Procurement, Project Management, and ultimately Construction. The **collaboration** that backed this Expo included 4 faculty, over 20 students, and 3 licensed engineers, as well as a number of local vendors and contractors who donated time, materials, and services. Practicing engineers hailed from a prominent design-build firm and one of the world's foremost concrete formwork providers. Moreover, to ensure a process that would yield a design that could be realizable in Haiti, the Expo created an **Innovation Exchange,** between its US university-based research and development of structural aspects, including full-scale prototyping, and operations in Haiti that would verify feasibility/constructability and identify non-structural finishes that best met their cultural expectations for a home. This Haitian team of 5 builders was led by a US-trained Haitian engineer, collaborating with in-country staff from the students' university.

The outcome of this Expo, while most tangibly evidenced by the **construction of two full-scale, 2-room (288 sq. ft.) reinforced concrete prototype homes**, included many other deliverables, such as various student-led concept refinements. However, perhaps the most important direct outcome was the complete set of structural drawings, budget analyses, and comprehensive assessments of these housing typologies to yield a standardized design that is already being replicated in Haiti by a local crew on the first of what will hopefully be many homes.

The **knowledge and skills gained** by the students in this process have given them a greater appreciation for the role of engineering judgment, various aspects of professional practice, and the importance of licensure – and they are better, globally-minded engineers for it. But ultimately, the true lessons the students learned through the Expo cannot be quantified in words, but by the changed men and women they have become.

[redacted] Innovative Housing Solutions for Post-Quake Haiti

Rendering of Prototype A, including stages of construction

I. PROJECT DESCRIPTION

This project (**The Expo**[1]), through partnerships between faculty, undergraduate students (from 9 different disciplines), licensed engineers, allied construction professionals, and their Haitian counterparts, allowed a team of over 20 undergraduate students to emulate the entire project life cycle over the Spring 2014 semester, vetting the constructability, feasibility and scalability of two reinforced concrete housing typologies for post-quake Haiti using full-scale prototypes on campus with mirrored activities in Haiti. Before describing in the Expo experience, it is first important to contextualize the problem the Expo Team was working to address: the **post-quake housing crisis**.

It is estimated that in excess of 250,000 people were killed in the January 2010 Haiti earthquake, hundreds of thousands more were injured, and approximately 1.3 million people were left homeless. This is attributed to the failure of a majority of the building stock in the affected regions, whose losses totaled an estimated **$3 billion**. As it is projected that **600,000 homes** will need to be reconstructed to meet the needs of this devastated nation, there is growing consensus that the recovery in the residential sector will only be accomplished by building local capacity to finance and execute the reconstruction of resilient homes. Unfortunately, the sad reality is that four years since the earthquake families have still no viable roadmap to do so, as their traditional masonry construction has proven too expensive to safely re-implement, leaving them indefinitely confined to their transitory shelters.

> "Positive examples of permanent housing solutions are scant. Too much focus has been placed on the construction of physical structures rather than on setting up the sustainable delivery mechanisms that will stimulate the creation of sustainable communities and provide investment sector."
>
> *--Oxfam International, Haiti*

Since March 2010, a team of students and faculty have been working toward building such local capacity by formulating an integrated process that empowers Haitian entrepreneurs to deliver dignified, engineered urban housing within that nation's informal economy. Their work has been informed by three years of personal reconnaissance that included over 100 forensic assessments of structural failures, interviews with 1400 internally

[1] The project's name is the "[redacted] Expo." Due to the anonymity requirements, [redacted] is blacked out of the title and the project will be referred to herein simply as the "Expo."

Expo faculty meeting with local construction crews

displaced persons (IDPs), and collective visioning of potential housing typologies with over a dozen architects, engineers and masons in a city in Haiti that was the effective epicenter of the earthquake. Anticipating that aid would in no way be able to meet this community's need for housing, the team's reconnaissance documented additional information needed to formulate locally-sustainable engineering solutions: construction material supply chains, skill sets of construction crews, and monthly revenue IDPs could direct toward reconstruction. This process yielded a constraints matrix with requirements for (i) **resiliency** against natural and man-made hazards, (ii) **feasibility** to ensure designs can be executed in Haiti, (iii) **viability** to earn the support of local stakeholders, and (iv) **sustainability** in light of the severe financial. This matrix defined a solution space in which the team of faculty and students began to explore potential housing typologies, arriving ultimately at an innovative reinforced concrete moment resisting frame (MRF) clad with lightweight, pre-cast concrete panels, supported by a business plan that could commercialize its local retail and construction in Haiti.

As the team began to share their work with IDPs in Haiti, the urgency created by the growing interest and enthusiasm made it clear that the team would need to swiftly move from conceptual design to a detailed and fully vetted engineering design, supported by a full-scale prototype to establish the constructability, repeatability and scalability of the housing concept. **The Expo** thus serves as this venue. The **Expo Team** relies on an **Innovation Exchange** between bases of operations in both the US and Haiti to divide operations. By recognizing the existing infrastructure and capacity for **Research and Development (R&D),** the campus was the logical home for R&D and prototyping of the structural aspects of the design, while Haiti would provide the ideal laboratory to practically verify feasibility/constructability and identify non-structural finishes that best met cultural expectations for a home.

The stateside Expo Team included university students and faculty who focused initially on the detailed design of various structural features of this new housing model, including:

1. design of 5 different **panel configurations** with a simple and efficient pre-casting scheme
2. conception and design of a **customized foundation** for the geotechnical conditions in Haiti
3. development of a high-quality **prefabrication process** for steel reinforcing cages
4. fabrication of **low-cost formwork** for the structural frame and panel production
5. design of simple connection details for the **panel attachment** to the structural frame

In this process, the students used a combination of structural analyses, design by prescriptive-code, half-scale prototypes and full-scale component testing. The strategies, lessons, and designs developed in the university environment were fed down to Haiti in real-time for evaluation and execution by a team of community builders and university staff, creating a valuable feedback loop.

Meanwhile, the students partnered with US private sector leaders in design-build, including those with experience in reinforced concrete housing typologies for the developing world, to vet the

Expo Team constructing Prototype B on campus

constructability, feasibility and scalability of their concepts, working collectively, with Haitian feedback, to arrive at a final design and construction strategy for a two room, **288 sq. ft. starter home** with a covered porch that could be expanded in size over time as a family accumulated more savings. In order to ensure objective evaluation of the proposed housing model as the best possible solution for these families in Haiti, the private sector partners introduced an alternate housing typology: a reinforced concrete cast in place (CIP) load bearing wall system popularized in Africa. Through collaboration with their licensed engineers, the students worked to realize a design, pricing and construction sequence for this competing housing model.

However, considering the need for any viable housing model to be executable in Haiti by workers with minimal skill sets, while still achieving requisite quality control in an environment where oversight is lacking, the US team recognized the necessity to further vet the feasibility of their plans by having crews of students without formal construction experience build a **full-scale prototype** of each home on campus using only the proposed structural drawings and construction sequences. The resulting prototypes would then be used subsequently to raise awareness about the housing crisis and the teams' efforts to deliver lasting solutions. In one week's time these two houses were erected by student construction crews, under the supervision and guidance of their partners.

The end result of this semester-long effort was the realization of two full-scale prototypes with identical floor plans (Prototype A: MRF, Prototype B: CIP) that now stand on campus as a focal point for the university's commitment to Haiti's recovery. But more importantly, the complete sets of structural drawings, budget analyses including both US and Haitian unit and general conditions costs, and scoring of each prototype's compliance with the aforementioned constraints matrix now provides a standardized design that is already being replicated in Haiti by a local crew on the first of what is hopefully many homes.

II. COLLABORATION OF FACULTY, STUDENTS AND LICENSED ENGINEERS

Although the end product of this effort ultimately serves Haiti, by executing two full-scale prototypes in the US, the students were able to dramatically transcend the typical classroom experience by enacting an actual **microcosm of the life cycle of a typical project** on campus. This included all the project phases listed in the inset box, ultimately culminating in the construction and documentation of as-built details. At each step of this life cycle, the students directly benefitted from the insight, experience and mentorship of professional engineers and allied professionals in the construction industry, who held them to a high

PROJECT PHASES

Conceptual Design, Concept Refinement, Material Testing, Code-Compliant Design, Structural Drawings, Fabrication, Construction Sequencing, Site Planning Permitting, Budgeting/ Quantity Estimation, Procurement, Project Management, Construction

Members of Expo Team posing after casting Prototype A

professional standard that tangibly demonstrated the expectations placed upon practicing engineers every day. By then having the feedback from formally trained engineers in Haiti[2], the students were able to gain a cross-cultural perspective of true solutions being those that can ultimately be executed in their final application and even benefitted from an exchange of ideas, e.g., Haitian construction crews sending you tube videos to teach feasible and efficient techniques to bend stirrups.

This interaction was facilitated through a number of formal academic and informal mentoring environments, the most formal of these being the department's senior capstone design course, where direct weekly mentorship and instruction was provided by three PEs (one of them faculty) to guide the expectations for a formal design process. This was complemented by a less structured directed studies course, overseen by two additional faculty, which integrates the efforts of over 20 undergraduate students from five majors to address the wider R&D aspects of this effort and integrate the private sector partners from both Haiti and the US. This course uses a hierarchical organization so that senior leaders meet weekly with the faculty and then self-organize and direct the underclassmen in the course. The US private sector partners included a prominent design-build firm and one of the world's foremost concrete formwork providers, both from major cities in the region. Both firms brought PEs and EIs to the process from within their organizations, as well as from collaborating subcontractors. Thus direct PE mentorship was provided for all structural designs/drawings, site planning and construction scheduling. These firms additionally provided project managers, firm principals, and superintendents throughout the project to step from design through construction. The Expo team includes members of a course on International Development, which supported students in traveling to Haiti to formulate recommendations on how to best integrate this housing model within the evolving housing policies in-country.

Because of the geographic separation between the students and the US private sector partners, outside of the week of construction when face-to-face interaction was possible, student leaders conducted weekly conference calls with the firms and supervising faculty, using file sharing services to exchange drawings and maintain detailed agendas, meeting minutes, punch lists and schedules, following up with personal emails and phone calls as needed. Interactions with Haiti relied primarily on email, video conferencing and mobile communications, outside of one week-long visit by two students. By the end of this experience, it was clearly evident, to the faculty and students alike, that such an ambitious semester-long project could not have been realized without the invaluable experience and insight brought by licensed engineers and allied construction professionals.

[2] Note: Haiti does not have a formal licensing program for engineers, but engineers who are formally trained in the US are regarded as the highest level of professionals in their community.

III. BENEFIT TO PUBLIC HEALTH, SAFETY AND WELFARE

Make-shift shelters occupied by IDPs in Haiti

The existing construction practices and structural typologies in Haiti were proven vulnerable in the 2010 Earthquake. Sadly, families cannot afford properly confined masonry homes as a means to address these vulnerabilities and many are even reluctant to reconstruct with masonry altogether, leaving hundreds of thousands indefinitely confined to transitory shelters. These constitute harsh living conditions with a multitude of impacts on quality of life, prosperity and health. The Expo, operating primarily on self-organized undergraduate student teams, demonstrates how innovation in typologies and construction technologies can find solutions to such daunting challenges. Thus, in developing these solutions, the students on the Expo Team directly contributed to the immediate safety of households in Haiti through their aseismic design, which ensured compliance with all locally-imposed engineering constraints and international seismic provisions such as ASCE 7-10 and ACI 318-11. Moreover, through their concern for non-engineering constraints to lower the cost of safety for the masses, quality of life within these communities can be affected on a large scale. Because so many were previously priced out of the market for a safe home, this design has been enthusiastically received by the IDP population in Haiti, where hundreds of families have already enrolled in savings programs. For this reason, the project's emphasis not just on the design and construction of prototype homes on campus, but rather on the formulation of a **housing system and process**, shaped not only the current construction of the first home in Haiti, but can empower reliable replication of this process many times over.

For this team of students, who held themselves to a high level of personal accountability considering the end goal of this project, simply reading about the failure mechanisms in the 2010 Haiti Earthquake was not enough. Instead, they sought out their own funding to conduct personal reconnaissance in Haiti and other neighboring countries, with similar construction practices and lack of code enforcement, to reinforce for themselves the existing vulnerabilities in masonry construction and how even thoughtful designs can be compromised in construction due to a lack of quality control or resources. This underscored for them the responsibility of engineers to provide designs that can be executed, in light of both the available skill sets and budget. Failure to do so, in this instance, has deadly consequences that can promote dangerous practices, e.g., feeble attempts to execute confined masonry even when having only a fraction of the budget necessary. Ultimately, the end result, for all involved, was a valuable lesson in how sound engineering judgment and a return to engineering fundamentals was necessary to provide the requisite safety and cost savings.

Based on their personal reconnaissance in developing countries, the students realized that there is a chasm between the engineering available to these nations, and the engineering that is needed to broadly protect their citizens' lives. This project provided tangible evidence of how engineering can close that chasm by being a catalyst for innovation and change, to not just design common typologies, but to invent new systems for a unique context. Doing so required a great deal

from the students, all of whom voluntarily joined this effort and self-organized to execute various design and prototyping activities. In the process they learned a valuable lesson: they can be the catalyst that drives a new paradigm that is so desperately needed, not just in Haiti, but throughout the world's slums where a billion individuals vulnerably reside.

IV. MULTIDISCIPLINARY PARTICIPATION

DISCIPLINES
Civil Engineering
Mechanical Engineering
Electrical Engineering
Architecture
Political Science
Int'l Development Studies
Liberal Studies
Business (Marketing)
Social Entrepreneurship

The Expo involved over **20 students from 9 different majors and minors** (see inset box), primarily hailing from civil engineering. The project receives advisement from the campus institutes for global development, who facilitated student travel to Haiti to meet with major actors in housing at the governmental and non-governmental level and formulate recommendations for formal integration of this housing model in their recovery plans. The program of liberal studies similarly facilitated student travel to Haiti and guided research on community attitudes and adoption barriers for this new housing model, all critical to identifying the many non-engineering constraints that defined the solution space. Finally, the university's master's program in engineering entrepreneurship incubated the business plan for the housing model, including all aspects of market research, finance and commercialization, under the mentorship of a renowned social entrepreneur. These non-engineering perspectives are not only essential for buy-in and uptake in Haiti for the ultimate goal of building local businesses around building homes, but also to build support for this approach to the Haiti housing crisis through marketing and public awareness campaigns.

While the design of the home has technical roots within structural engineering, the realization of this project across the entire design-build life cycle incorporated other civil engineering sub-disciplines, including geotechnical, materials, and most critically, construction/project management. Moreover, as the private sector partners themselves brought a wide array of backgrounds, including civil/structural engineering, architecture, project management, construction management, and accounting, the students benefitted from a diversity of mentoring styles, experiences and skill sets to realize that no problem can truly be solved in a disciplinary silo.

V. KNOWLEDGE/SKILLS GAINED

Expo Team tilting up panels on Prototype A

Through close collaboration with licensed engineers, other allied construction professionals, and practitioners in international development, as discussed previously in Section II, the students were able to emulate the entire project life cycle in one semester, from conception to construction, refining their practical skill sets in a variety of engineering and professional dimensions. In this manner, the Expo was a microcosm of the professional

practice they will soon embark upon. These skills gained included technical capacities in software (AutoCAD, Revit, Sketch Up, SAP2000), proficiency with codes and standards like ASCE 7-10 and ACI 318-11 (seismic detailing, in particular), and best practices in project management, including clearly identifying and communicating roles and responsibilities for a diverse team. By incorporating two prototype designs into the Expo, the students also recognized that a thoughtful and rational approach to evaluating competing options is essential to arriving at an outcome that best serves the client, in this case Haitian IDPs.

In particular, forcing the students to physically fabricate and construct all aspects of their design in full scale, dramatically enhanced their appreciation for all aspects of project management, the need to maintain accurate and fully notated drawings, and ultimately the engineer's obligation to deliver an efficient and constructible design. More importantly, the experience of managing a major construction project on their own campus, independent of their interactions with Haitian counterparts, underscored how many complex dimensions outside of engineering interact to realize a project with hard deadlines and considerable coordination demands. The most valuable moments in this process were born unintentionally as conflicts or delays surfaced, requiring students to "think on their feet" given the accelerated timeline of their construction process (1 week). Working alongside patient and experienced practitioners at each stage of this process ensured that they found positive role models to emulate, even in the most stressful moments.

Because of the larger context for this experience, in Haiti, students quickly appreciated that multidisciplinary collaborations are essential to discovering lasting solutions that fully navigate identified constraints. For the Expo Team, this problem represents a significant ethical challenge related to the engineer's role in responding to the injustices that afflict the world's poor. Their approach to this problem reflects a belief that the only ethical solution is one that provide safes and contextually-appropriate solutions that do not foster reliance on foreign aid or propagate practices proven vulnerable in the 2010 earthquake. To that end, their voluntary travels to Haiti to meet with government and non-governmental actors in the housing sector to ensure the outcome of this project would effectively integrate with evolving national policies and frameworks was the ultimate testimony to the life-changing learning experience they were a part of. Indeed they now have a greater appreciation for the role of engineering judgment and various aspects of professional practice and the importance of licensure -- and are better, globally-minded engineers for it. But ultimately, the true lessons the students learned through the Expo cannot be quantified in words, but by the changed men and women they have become.

"The Expo taught us that engineering is not just science, math and technology, but in the end, engineering is about people. It is about dignity and human rights and security and justice. Our stories are true stories about people, allowing us to connect our calculations and numbers to movement and action… …THIS is the heart of engineering." *--Senior A & MRF Foreman*