Designing and Developing Sustainable Housing for Refugee and Disaster Communities

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I. Introduction

Over a million Haitian men, women, and children lost their homes in the 7.0 magnitude earthquake in 2010[3]. In response to this event, the international humanitarian community deployed tents and built makeshift communities. Even though these tents provided immediate shelter to the displaced people of Haiti, they were susceptible to flooding, intrusion of waterborne disease (cholera), and were extremely dangerous for women and children.

The number of families living in severe housing conditions due to war, natural disaster, and poverty is estimated to exceed one billion[4]. This is overwhelming. However, being overwhelmed is not the answer. Architects, engineers, business managers, and the local communities must find new solutions that apply appropriate technology to improve the lives of these poorly housed people. The inspiration for the establishment of Humanitarian House International[5] and the HHi House© came from the images of these communities and their suffering. There had to be an alternative housing solution to address the needs of these people, a need seen in refugee communities and urban slums around the world.

Today, few housing solutions address this gigantic challenge. In natural disasters and refugee camps tents are relatively inexpensive and easily deployed. They provide immediate shelter and some degree of privacy. However, the UN has stated that "on average a tent in a camp last 6 months while the camps last up to 12 years"[6]. Tents are not durable, lack raised floors, and are flimsy in severe weather. As these tent communities grow, they become breeding grounds for filth, disease, and crime. The lack of sturdy shelter creates much of the challenge. Instead of creating communities, there is a scatter shot of housing. The Humanitarian House International vision is to use the HHi House as the starting point for creating sustainable, culturally sensitive longer-term desirable communities. The HHi House not only provides the essentials but also as part of a planned community will enable the residents an opportunity to prepare a better future. The underlying idea is not to warehouse displaced, impoverished people but to create a new community where education and self-reliance will grow to meet new challenges.

Currently there are two HHi House models, The Emergency Shelter (ES) and the Long-term Dwelling (LTD). The two designs share the same dimensions, framing, and flooring. The ES has a plastic membrane sweater that drops over the frame. In 8 hours, this unit replaces the earlier deployed tents and literally lifts the residents off the ground.

As the community stabilizes, an upgrade to the LTD version of the HHi House occurs with the removal of the sweater and the implementation of corrugated plastic roofing panels and the installation of the floor/wall panels into the walls. A door, adjustments to the interior with beds, and kitchen or bathroom specific components are optional and can be added during or after the upgrade.

In 2011, the first prototype of the envisioned solution was designed and built in Denver, Colorado in Stuart Ohlson's front yard. This prototype was followed by advanced designs and prototypes, 2-4. Each prototype included modifications to the framing components, the coverings, and the floor. Prototype 5 represents the last prototype before placing the HHi House into a field trial in a representative third world community.

II. Design Elements, User Stories, Assumptions and Approach

A. Approach

The HHI team uses a modified version of the Lean/Agile[7] methodology. This approach focuses on designing and building specific elements with reduced intervals. Instead of specified requirements, the project development utilizes User Stories. These stories give the team flexibility to test a variety of ideas and adapt the design throughout the prototyping process.

To date, the team is building Minimal Viable Product (MVP) 1.

MVP 2 represents the field trial configuration and MVP 3 represents the go-to-market launch configuration. Both of these designs will be based upon the learnings and knowledge gained during the preceding phase.

B. Design Elements, User Stories, and Assumptions

The following User Stories are specific to MVP 1.

Design Element	***User Stories***	***Assumptions***
Size	1. The house will accommodate the target occupancy number of 7-9 adults. 2. The house will be sized to provide space for storage, daytime living, and nighttime sleeping.	
Occupancy	1. The house will sleep between 7-9 average size adults.	
Durability	1. The house will withstand winds of 80 MPH. 2. The house's materials will not breakdown in 90% + humidity or 100 degree (F)/37.7© temperature. 3. The roof trusses will withstand heavy torrential rains in excess of 6 inches per hour. 4. The floor panels will support a load of 30 pounds per square foot (PSF) 146.47 kilos per .09 square meters.	
Climates	1. The house will provide durable shelter in equatorial and sub-tropical regions around the world.	Like a tent, the HHi House can provide shelter in colder weather but like a tent lack adequate insulation from the cold.
Frame	1. The house will be framed with strong adaptable material that is easy to install and maintain. 2. The entire frame and all floor and ceiling joists can be installed by no more than two people in 1 day. 3. The installation of the frame will require no special tools, e.g. saws, hammers, or wrenches. 4. The frame will extend below the floor to support the house. 5. The frame extensions will be adjustable and adaptable to deal with local grade differences.	There are many situations where the house will be on hillsides or irregular parcels of land.
Floor	1. The house will have a lightweight, easy to install floor. 2. The floor will be off the ground by at least 12 inches/30.5 centimeters. 3. The floor will support 30 PSF/146.47 kilos per .09 square meters. 4. Each floor panel will weigh less than 5 lbs/2.3 kilos. 5. The floor and the frame can be leveled using simple adjustment settings.	The floor must be high enough to allow inches of water to flow underneath without touch and saturating the interior.

Design Element	***User Stories***	***Assumptions***
	6. The floor panels will be used as the packing container for the other components. 7. The flooring material will impermeable to water, rot, or mold. 8. The floor will be easily cleaned with either a dry broom or a wet mop.	
Roof	1. The house's roof will protect the occupants from rain, wind, and sun at all times. 2. The roofing material will withstand rain storms of 6 inches of rain/hour and 80 MPH steady winds	
Ventilation	1. The house will provide the occupant multiple techniques to increase or decrease the airflow.	
Uses	1. The house will be used as primary accommodations for families and individuals. 2. The house can be adapted and becomes a support building, a storage facility, or adapted according to the user's needs.	The HHi House is a living space for people. However, HHI recognizes the adaptability of the space and its potential to integrate multiple HHi houses into unforeseen configurations.
Installation	1. The house will be installed in less than one day by no more than two individuals without	

Design Element	***User Stories***	***Assumptions***
	specialized tools.	
Maintenance	1. The house's components can be replaced with spare parts without any specialized tools. 2. The parts' dimensions will conform to the exact design of the base configuration components.	
Price	1. The price of the House will be no more than $2,000 US for the ES model and no more than $2500 US for the LTD model.	Today's benchmark price is the Shelter Box[8] tent system that retails for ~$500 US inclusive of the emergency kit packaged with the tent.
Packaging	1. The house's components will be designed to fit into a standardized shipping container compliant with shipping and transportation industry best practices. 2. The emergency house will be packaged in a 40" x 40" x 80" (101.6x101.6x203 .2 Centimeters) integral or equivalent lightweight secure container	Decisions on packaging will incorporated into Minimal Viable Product 2 User Stories, e.g. field trial
Materials	1. All materials used in the house must meet the durability standards described in the user stories.	

Design Element	***User Stories***	***Assumptions***
	2. The construction material will not be commodity based to reduce theft at the site. 3. The materials must be strong enough to meet the tolerances of the design and must be lightweight to allow for reduced shipping costs and easy movement during construction.	
Standards	The design will conform to standards.	

III. Prototype Design and Development

Figure 1: HHi House© Prototypes 2, 3, and 4 (bottom to top)

A. The Design

The HHi House (Figure 1) design utilizes a contemporary space frame structural system found in efficient, lightweight structures. The choice of this design was based upon the ease of construction, the simplicity of the design, and the design's historic structural strength.

The HHi House dimensions of 13.4 feet square provide total space of $172ft^2$ /$52.4M^2$. The size of the house is large enough for seven to nine adults to comfortably live and sleep. Space for storage and meal preparation, dining space, and general living space is factored into the design.

The current designs and prototypes use two inch PVC tubing connected using a proprietary designed connector, the Octajoint©. This connector allows for 0°, 45°, and 90°connections in a 3 dimensional star-like configuration. The team investigated other materials as alternatives to plastic/PVC, these included aluminum, and fiberglass to emulate the lightweight approach seen in tents. However, PVC or equivalent plastic tubing is available throughout the world is strong, light, and inexpensive. It is very easy to modify and cut. In addition, unlike aluminum, it is not a commodity trading on the world market and less susceptible to theft and resell. Bamboo was proposed due to its environmental friendly characteristics, its strength, and affordability. However, at this time the lack of uniformity in bamboo size and shape make it unattractive for this phase of the HHi House development.

The floor/wall panels have been the biggest challenge for the team. The user stories have multiple elements: lightweight, strong, maintainable, and surface durability. The prototype panels all use a snap in approach with the panel having a lip that holds the panel in place against the PVC frame. The current panels are made from Oriented Strand Board (OSB)[9]. This is not an acceptable material and is only for modeling the configuration. Plastic panels replace the OSB in Prototype 5 and MVP 2. The current panels will be replaced with a injected or thermo formed plastic panel. The design for these panels is complete with manufacturing pending.

B. Prototypes – Goals, Activities, Location, Testing, Evaluation, and Results

The following are the design, development, and prototype implementations through June 2014.

Prototype 1 (Construction completed 2011)

- Goal: To create a simple housing design that offers a stable, durable housing alternative to victims in natural disasters like the Haitian earthquake. Prototype 1 conceptualized the design and provided an evaluation platform for size and shape.
- Activities: After remotely observing the destruction of the Haitian Earthquake and the world's response using tents as primary shelter drawings were drafted to create a design the (yet to be named) HHi House. The sketches led to the creation of the first house using PVC tubing as the frame connected using crude plywood connectors and ¾-inch plywood panels for the flooring. The exterior covering material and structure was investigated with the decision to use a durable weatherproof plastic membrane, e.g. DuPont's Tyvek®.
- Location: Stuart and Lori Ohlson's Backyard in Denver, Colorado
- Testing: The testing of the frame and structural components was conducted on a "trial and performance" basis following observations and recommendations of a licensed structural engineer.
- Evaluation: The first design measured and tested the assumptions of the simplicity of the assembly, and the

structural performance of the house. It confirmed whether a house with the target goals could be built.

- Results: The first design identified the need to change the connector materials. The plywood connectors were not durable, difficult to configure and heavy. The PVC tubes worked well. The rectangular rather than the square floor design was not sustainable.
- Prototype 1 demonstrated the parameter design met the goal of accommodating 7-9 adults, the structural frame would support the anticipated load, and the floor with significant design modification would provide the elevation to lift the residence off the ground. Color-coded connectors and tubing identify the three-tiered framework that allows quick assembly via simplified graphic instructions.

Prototype 2 (Construction completed 2011)

- Goal: To design and fabricate the Emergency House model and utilize 45degree connectors in plywood and wood dowel materials for 14 possible concentric tube connections
- Location: Sustainability Park, Denver, Colorado
- Testing: The model was a full-scale assembled structure subject to weather, rain, wind, and snow utilizing wooden components intolerant to moisture and fabrication irregularities.
- Results: The team manually fabricated 111 plastic connectors and proceeded on with construction of Prototype 3.
- Evaluation: After months in the heat and sun it became apparent that wood was not an acceptable material for connectors. Prototype 3 would use a redesign using PVC plate PVC tubular dowels.

Prototype 3 (Construction completed 2011)

- Goal: To create, deploy, and evaluate plastic connectors as the connectors for the tubular PVC. The connectors will be glued together and joined to the PVC with glue.
- Location: Sustainability Park, Denver, Colorado
- Testing: The plastic connectors replaced the wood connectors (Prototype 2). These connectors were used throughout the house to connect wall 90° framing, 45° wall bracing, and the now meter^2 floor panels. The use of plastic cement welding to create the connectors and connect to the PVC tubes was time consuming and negated disassembly.
- Results: The manual fabrication of interlocking octangular PVC plates to create friction assembly and locking clips illustrated the desired concept but lacked the ease of implementation critical to achieving the project's goals.
- Evaluation: The connector design failed to meet any of the key requirements: It was difficult to implement, labor intensive, and lacked the necessary rigidity. The team chose to abandon this approach and move to an injected molded connector.

Prototype 4 (Construction completed 2012)

- Goal: To manufacture and implement plastic multi-point connector (Octajoint©) to replace the previously tested wood and plastic connectors
- Location: Sustainability Park, Denver, Colorado
- Testing: The Octajoint© was implemented into the configuration. The connector design worked well and allowed the PVC tubing to snap-in to the joint easily and securely. This design created a very strong super structure and stabilized the frame, eliminated sway, and withstood environmental changes including high-winds, snow, and rain. The joints and associated floor PVC floor joists supported 200 lb. adults walking on them without any visible stress or strain over a 2-year period. This connector fulfilled the assembly expectations but it requires excessive manual shaping of PVC plates to integrate it into the structure.
- Results: The new connector demonstrated the desired flexibility but the anticipated cost of manufacturing, the durability of the clips (part of the joint design), and the challenge of modifying the ends of the PVC tubes makes this an unacceptable long-term solution.
- Evaluation: The moment arm of the Octajoint© connectors is not strong enough to deal with the stiffness that is required for superficial lateral support. The team plans to discard Octajoint and examine other options for greater connector simplicity and lateral stability.

Prototype 5 (Pending – Target Construction Date October 2014)

- Goal: To manufacture and implement a tubular connector for internal connection to tubular PVC framework

  To manufacture, install, and test a new floor/wall panel that is lightweight, strongest enough to support the customer story occupancy of 7-9 adults, and at a cost of less than $3/panel.
- Location: Sustainability Park, Denver, Colorado
- Testing: Horizontal load testing will be performed by Martin/Martin Engineers, Denver Colorado.
- Results: Prototype 5 substantially fulfills design requirements initially established including a 10-year PVC (protected) structural framework.
- Evaluation: Assuming Prototype 5 passes the horizontal tests, the new connectors prove durable and stable under a load test, the floor/wall panels meet the

design criteria, and the assembly/disassembly goals are met the HHi House will be placed into field trial in the summer of 2014.

C. Current (June 2014) Technical Specifications

- Exterior Dimension – 13.33′x13.33′
- Height at Roof Peak – 10.5′
- Current weight – 1200 lbs.
- Launch weight – 800 lbs.
- Components (Number of Units) – Total 142
    - PVC tubing - 92
        - Floor and Wall: (Length) – 40″
        - Frame supports: (Length) - 12″
    - Floor/Wall Panels (Prototype 5) - 28
    - Connectors (Prototype 5) - 114
    - External covering:
        - Emergency Shelter –
            - 1 door
            - Weather Resistant Plastic Sweater - 1
        - Long Term Dwelling
            - Corrugated Plastic Roof Panels- 20
            - Wall Panel - 26

IV. Next Steps

The team is moving forward with the goal of deploying up to five HHi Houses into a target field trial location in 2015. The desired location will be in a community in Central or South America with a need for this type of structure, a community willing and able to provide feedback, and a location within 10 air travel hours of Denver.

In order to achieve this goal the following project elements must be completed.

1. Floor/wall panel: Stress and climate testing after funding and then manufacturing of the current design of the floor/wall panels.
2. Connectors: The Octajoint connector could be used in field trial but an alternative rounded connector has been identified and may be ready for Prototype 5 and the engineering tests.

3. Testing, Engineering, and Forensic analysis will be the last activity and gate prior to initiating a field trial launch. An engineering firm in Denver is prepared to do testing and evaluation once Prototype 5 with the new floor panels is available. This testing will include:
    - Stability and durability testing
    - Climate testing
    - Configuration testing
    - Floor/wall panel load testing

V. The Team and Program Methodology

Humanitarian House International started out as one man's vision to change the world by building better houses for families living in disaster areas and in severe poverty.

At the start, there was no team just a handful of close friends who shared the vision. Four years professionals with extensive product development, marketing, operations, design, engineering, and social media experience created a dynamic, energized team. As of June 2014, all of the team members are volunteers who commit between 2-20 hours of their time per week to achieve the dream.

Humanitarian House International LLC is a for profit company today. However, it is the team's plan to create a non-profit company to improve fundraising and to align with the humanitarian vision.

The team uses a traditional program management methodology combined with Agile[7] concepts to define work activities. The team meets weekly, has extensive short-term project goals and activities, and assigns work to the appropriate team members.

Funding is the other major constraint affecting the team's ability to move from one prototype to the next. The project team has been very successful asking and receiving small donations of services from various engineering firms and manufacturers. However, some components require capital investment in injection molds and tooling. These are hard costs. A crowd funding campaign was launched in May 2014 with an end date of July 2014. It is too early to know whether this approach will be successful.

The team has begun building a social media presence on Facebook, LinkedIn, YouTube, and its own web site. It is too early to judge the success and effectiveness of the effort.

VI. Future Configuration

The design team plans for the integration (through business collaboration and partnerships) of rainwater and waste management systems, and solar power collection (or other energy systems), and waste treatment systems for near-term utility systems. The same affordability, ease-of-installation, and durability stories will be applied with the vision to have HHi House worldwide communities. These thriving communities are clean, safe, and long lasting (over 5 years).

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