Designing and Developing Sustainable Housing for Refugee and Disaster Communities

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Abstract

Typhoons, earthquakes, and war displace millions of people. Typhoon Haiyan left 1.9 million homeless [1]. There are over 2 million homeless Syrian refugees [2]. Housing these people is a challenge because these rapidly created emergency communities may last 12 years. Tents are the solution; they deploy fast and provide immediate shelter. However, they only last 6 months [3].

Colorado based Humanitarian House International [4] created the HHi House© (pronounced "high house") to solve this long-term housing and community creation challenge.

Victims of these terrible events need housing to cover their heads, protect their families, and provide security. The HHi House elevates the family off the wet and cold ground and gives them a drier living space. It accommodates up to eleven adults and withstands strong winds, rain, and offers a dry, easily cleaned durable, raised floor. The rigged wall version of the house provides for improved security and privacy.

The vision has the house as the cornerstone of a larger integrated, culturally sensitive, planned community that integrates with affordable water, waste, and energy systems. Unlike a tent, the HHi House is a durable, long-term housing solution that revitalizes communities and empowers the families in these communities.

This technical paper will describe the team's experience designing, engineering, manufacturing, and funding the HHi House. It includes a description of the five prototypes created to date, the learning from each phase, and a description of the structure and its components.

Keywords—housing, disaster, sustainable, structure, refugee, slum, adaptable, culture, floor, tent

I. Introduction

Over a million Haitian men, women, and children lost their homes in the 7.0 magnitude earthquake in 2010[5]. In response to this event, the international humanitarian community deployed tents and built makeshift communities. These tents provided immediate shelter to the displaced people of Haiti, but these tent communities were susceptible to flooding, intrusion of waterborne disease (cholera), and were extremely dangerous especially for women and children.

More than one billion families live in severe housing conditions due to war, natural disaster, and poverty [6]. 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 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, surprisingly 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 tents in a camp last 6 months while the camps last up to 12 years" [3]. Tents are not durable; families live and sleep on the ground, 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, long-term desirable communities. The HHi House provides a secure roof, walls, and a floor, and becomes part of a planned community enabling residents an opportunity to create a better future.

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 has a raised floor that literally lifts the residents off the ground.

As the community stabilizes, an upgrade to the LTD version of the HHi House occurs by removing the sweater and installing corrugated plastic roofing panels and rigid wall panels, (the framing remains unchanged). Optional modifications made after the upgrade to the HHi House include a door, adjustments to the interior with beds, and kitchen or bathroom specific components.

In 2011, Stuart Ohlson built the first prototype of the envisioned solution in the front yard of his Denver, Colorado home. Prototypes 2-4 followed over the next 3 years. 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.

This technical paper describes the user stories and design assumptions, the prototypes, and the learnings associated with each prototype. It concludes with a listing of the team's next steps and activities to move the HHi House from the prototype phase to a field trial.

II. Design Elements, User Stories, Assumptions and Approach

A. Approach

The HHi House 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 (Prototypes 1-5).

MVP 2 represents the field trial configuration and MVP 3 represents the go-to-market launch configuration. Information and knowledge gained from each phase creates modification to the next phase.

B. Design Elements, User Stories, and Assumptions

TABLE I
.USER STORIES FOR MVP 1

Design Element	***User Stories***
Size	• The house will sleep up to 11 adults. • The house provides space for storage, daytime living, and nighttime sleeping.
Occupancy	• The house accommodates eleven (11) average size adults.
Durability	• The house will withstand winds of 80 MPH. • The house's materials will not breakdown in 90% + humidity or 100-degree F/37.7C temperature. • The roof trusses will withstand heavy torrential rains. • The floor panels will support a load of 146.5kg/ M^2 (30 pounds per square foot).
Climates The HHi House can provide shelter in colder weather but like a tent lack adequate insulation from the cold.	• The house will provide durable shelter in equatorial and sub-tropical regions around the world.
Frame There are many situations where the house will be on hillsides or irregular parcels of land	• The house's frame will be strong adaptable material that is easy to install and maintain. • Two can people can install the entire frame including all floor and ceiling joists in one day. • The installation of the frame will require no special tools, e.g. saws, hammers, or wrenches. • The frame will extend below the floor to support the house. • The frame extensions will be adjustable and adaptable to deal with local grade differences.
Floor The floor must be high enough to allow inches of water to flow underneath without touching and saturating the interior.	• The house will have a lightweight, easy to install floor. • The floor will be off the ground by at least 30.5 CM (12 inches). • The floor will support 146.5kg/M^2 (30 pounds per square foot). • Each floor panel will weigh less than 6.8 KG (15 lbs.). • The floor and the frame can be leveled using simple adjustment settings. • The floor panels will be the packing container for the other components. • The flooring material will be impermeable to water, rot, and mold. • A broom or wet mop will clean the floor.
Roof	• The house's roof will protect the occupants from rain, wind, and sun at all times. • The roofing material will withstand torrential rainstorms and 80 MPH steady winds.
Ventilation	• The house will provide the occupant multiple techniques to increase or decrease the thru ventilation.

Design Element	***User Stories***
Uses 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.	• The house accommodates families and individuals. • The house can be adapted to become a support building, a storage facility, or adapted according to the user's needs.
Installation	• Installation of the house takes less than one day by no more than two individuals. It requires no specialized tools.
Maintenance	• Replacement of the house's components with spare parts occurs without any specialized tools. • The parts' dimensions will conform to the exact design of the base configuration components.
Price The benchmark price is the Rotary Club International's Shelter Box [8] tent system that retails for ~$500 US inclusive of the emergency kit packaged with the tent.	• The price of the House will be no more than $2,000 US for the ES model and no more than $2,500 US for the LTD model.
Packaging MVP 2 designs will assess the best packaging approaches as part of the field trials.	• The house's components will fit into a standardized shipping container compliant with shipping and transportation industry best practices.
Materials	• All materials used in the house must meet the durability standards described in the user stories. • To reduce theft at the site, the construction material will not be a commodity, e.g. aluminum. • 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 published international housing 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 truss 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 inherent structural strength.

The HHi House dimensions of 13.4 feet square provide total space of 16.54M^2 (178ft^2) (These are centerline dimensions.). The size of the house is large enough for up to eleven adults to comfortably live and sleep with space for storage, meal preparation, and dining.

The current designs and prototypes use two inch PVC tubing (50MM metric equivalent) connected using a proprietary designed connector, the Octajoint© (Patent Pending) (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 is available throughout the world. It is strong, light, and inexpensive. PVC or equivalent plastic is affordable and available worldwide. (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, availability, and affordability. However, at this time the lack of uniformity in bamboo size and shape make it unworkable for this development phase of the HHi House.

The floor panels have been the biggest challenge for the team. The user stories have multiple design 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 an injected or thermo formed plastic panel. The design for these panels is complete with manufacturing pending.

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

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 seeing and reading about the destruction of the Haitian Earthquake, and the world's response using tents, the primary shelter drawings were drafted to create a design of 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 front yard 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 floor panels needed to be redesigned as squares for uniformity and fit in future models.
- Prototype 1 demonstrated the design met the goal of accommodating eleven adults (space and weight), 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 helped installers identify the three-tiered framework for quicker assembly.

Prototype 2 (Construction completed 2011)

- Goal: To design and fabricate the ES model and utilize 45-degree 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 65 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 feature a redesign using PVC tubular plates.

Prototype 3 (Construction completed 2011)

- Goal: To create, deploy, and evaluate plastic connectors to connect to the PVC tubes. 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 square-meter 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 plastic 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 into the joint easily and securely. This design created a very strong super structure, stabilizing the frame, eliminating sway, and providing improved weather resistance.. The joints and sub-flooring supported 200 lb. adults without any visible stress or strain over a 2-year period. This connector fulfilled the assembly expectations, but it required 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 made this an unacceptable long-term solution.

- Evaluation: The current star extenders(moment arm) of the Octajoint© connectors are not strong enough to deal with the stiffness that is required for sufficientlateral support. The team plans to discontinue use of the 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 panel that is lightweight, strong enough to support occupancy of up to 11 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 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 2015.

User Experience and feedback: Several experts provided feedback on the design... These experts include: Indian and Cambodian humanitarians, refugees living in the USA from the Sudan and Burma (Myanmar), Fulbright Fellows with extensive experience in Filipino culture and housing, and South American humanitarians attending the "2013 Hemispheres Conference in Denver, Colorado:".

The feedback has been supportive.

- The users felt the size of the unit was excellent, and its internal configuration permitted modification based upon the occupant's needs.
- The floor and the ability to level the floor differentiate the structure from tents and other structures.
- The ability to construct and modify the HHi House without specialized tools was very important.

The team continues to engage local and international experts in assessment of the structure and the goals of the team. This is a critical element in the Lean/Agile design and development methodology.

C. *Current (June 2014) Technical Specifications*

TABLE II
DIMENSIONS FOR PROTYPE 5

COMPONENT	***DIMENSION***
EXTERIOR	3.96M x 3.96M (13.33 FT X 13.33 FT.) or 16.54 M^2 (178 Ft^2)
HEIGHT	3.04M (10 FT) (FLOOR TO RIDGE)
CURRENT WEIGHT	544.31 KG (1200 LBS.)
LAUNCH WEIGHT	362.87 KG (800 LBS.)
TOTAL NUMBER OF PACKAGED COMPONENTS[A]	183

[A] The component count is for the ED model.

TABLE III
TECHNICAL COMPONENTS FOR PROTYPE 5

COMPONENT	***DIMENSION***	***QUANTITY***
FLOOR/WALL TUBING	Length: 1M (40 inches)	118
FRAME SUPPORTS	Length: .3M (12 inches)	25
FLOOR	Meter x Meter	74
CONNECTORS	NA	65
TYVEk® SWEATER[A]	NA	1
ROOFING PANELS (LTD ONLY)[B]	NA	20
WALL PANELS (LTD ONLY)	Meter x Meter	24

[A] The sweater is used with the ES model. It includes one door, 7-screened windows with Velcro® closures.

[B] The roofing and wall panels replace the sweater in the LTD model.

IV. Future Configuration

The design team plans for the integration (through business collaboration and partnerships) of rainwater and waste management systems, solar power collection (or other energy systems), and potable water systems. The team has deferred integrating these capabilities until the successful completion of the engineering evaluation and the deployment of the first field trial sites.

V. Conclusion

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 that is willing and able to provide feedback, and a location within ten air travel hours of Denver, Colorado.

Outstanding MVP 1 Activities:

1. Floor panel: Once fund raising and manufacturing are complete, the team will complete stress and climate testing of the current plastic floor design.
2. Connectors: The Octajoint connector is available for the field trial but an alternative rounded connector may be ready for Prototype 5 and the engineering tests.

3. Testing, Engineering, and Forensic analysis will be the last activity prior to initiating a field trial. A Denver engineering firm will test and evaluate the HHi House once Prototype 5.

   This testing will include:
   - Stability and durability testing
   - Horizontal and vertical load test
   - Climate testing
   - Configuration testing
   - Floor panel load testing

THE TEAM AND PROGRAM METHODOLOGY

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

Day one, there was no team, just a handful of close friends who embraced the vision of improving the lives of millions. Over the following four years, professionals with extensive product development, marketing, operations, design, engineering, finance, and social media experience created a dynamic, energized team. As of June 2014, all of the eleven-team members are volunteers who commit between 2-20 hours of their time per week to achieve the dream.

In July 2014, Humanitarian House International, Inc. became a not for profit company (in the United States this is important due to the tax advantages granted to contributors to these type of humanitarian projects.).

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

Funding is the 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 launched in May 2014 ending July 2014 raised 15% of the $50K goal (the team believes lack of not for profit status was a major impediment). The team has begun building a social media presence on Facebook, LinkedIn, YouTube, and its own web site. The not for profit status corporation opens the door for grants and similar funding which will be pursued.

ACKNOWLEDGMENTS

A project of this complexity could not progress without the assistance of numerous friends, family, and industry peers. The Humanitarian House International team thanks:

- Bill Kugler, Bison Innovative Products
- Ken Short, KTM Woodworking
- John Price, RD Specialties, DuPont USA,
- John Baker, Lockheed Martin
- Sam Gary, Gary Oil
- Harry Lewis, Retired
- Ed Ryan, Sustainability Park Denver, Colorado
- John Nix, Associated Thermoforming Inc.
- Scott Wilson, Front Range Tooling
- Chris Turnbull Grimes and Mike Barrett, Martin/Martin Engineering
- Red Line Museum Denver, Colorado
- Denver Housing Authority
- University of Denver MBA Team: Lizza Piper, Hillary Foster, Kathryn Ruggeri, Li Genzhong, Nicole Bernet, Paul Laesecke Advisor
- University of Oregon Denver Alumni Lunch Group, Greg Schowe leader
- Chan Valtha Thang , Businessman and Burmese Refugee, Louisville, Colorado
- Brian Oehler, Sustainability Expert, Denver, Colorado
- James Askew, Web Architect
- Paul Delisi, President Agile 3D Technology
- Jessica Feldman, President of JFeldman Design
- Dave Nosler, CPA
- Hollis Jef Pirkey, Video Producer & Artist
- Hank Peters, Financial Advisor
- Bill Shephard, Financial Advisor
- Tony Testolini, Sales Executive
- Stephanie Victa, Artist
- Wayne Tittes Sr., Home Builder

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