

# Disaster Relief Structural Framework: Transitional to Permanent

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**Abstract-**The 2004 Indian Ocean tsunami caused enormous devastation of homes, property, and infrastructure over vast coastal areas in more than eight countries in the region. The need for adequate shelter became an emergency of an unprecedented scale. Such a large scale of devastation presents an opportunity for engineers and architects to design without the normal restrictions of surrounding context and affect social change through good design.

Disaster Relief has been traditionally thought of in the realm of temporary structure, a structure that must be transported and erected at the place of the disaster. With the glut of aid, the humanitarian aid response to the 2004 Indian Ocean Tsunami was 14 billion US dollars. It certainly seemed to be the easiest answer to spend much on a structure, transport it and simply build it on site as the most efficient and timely answer. The failure comes in the ill consideration of the site and lack of appropriate sustainable solutions for a permanent shelter.

This research seeks to provide a solution for disaster relief that addresses a path from a provided transitional structure (usefulness measured in years not months) to a permanent architecture. It has also been shown that "...transitional" may be a misnomer, since many people never leave these homes, nor are "the homes upgraded". Relief structures have failed to anticipate needs of growth and daily life sustaining activities that go beyond the immediate need of shelter. The needs of shelter are predictable: roof, enclosure, windows, doors, etc... but there are shortfalls in considerations for expansion and needs for clean water, food storage and cooking and other life sustaining functions that go programmatically beyond "shelter". This gap in the goal and reality of aiding the affected people will attempt to be bridged by a modular framework that provides the flexibility to grow, improve and respond to make a quicker path to their normal permanent lifestyle.

The framework will address multiple needs in negotiating the requirements of a non-permanent transitional structure. It will accept numerous infill methods, both provided and vernacular. In addition to those basics, more frameworks can allow the plan to grow and be adapted to the different programs of each occupant and different typologies altogether, from individual to community level concerns. Special attention is given to such concerns as security, food cooking and distribution, and sanitation that are all typically omitted in a shelter design.

**Keywords-** *Disaster Relief Structure; Structural Framework; Transitional Structure; Permanent Structure Relief Shelter; Disaster Relief Architecture*

## I. INTRODUCTION

Two hundred million people (equivalent to two-thirds of the population of the United States) have been affected by natural disasters and hazards in the last decade... Ninety-eight percent of these victims are in the developing world [1]. Often, dwellings of the poorest are relegated to the most undesirable and intractable land outside urban cities and danger prone edges of coasts, rivers and flood plains. As populations continue to surge, soon to top 7 billion in the world, and rapid industrialization hits developing nations, more homes are pushed into areas poorly sited [2]. Then, natural disasters occur, destroying their homes. The frequency of these events has been increasing, if for no other reason than population increases make the probability of an event occurring in a populated area higher. Many times, these events come at the cost of lives and the infrastructure to make a rapid return to their lifestyle before the event. Circumstances then often dictate that they rebuild in the same manner and place, foretelling an eventually repeat of the disasters. There is, therefore, a need for an Architecture that is thoughtful and well designed in response to this issue.

December 26, 2004 the third largest earthquake on record occurred off the coast of Indonesia, striking there the hardest but also greatly impacting Sri Lanka, India, and Thailand. The resulting Tsunami was an order of magnitude worse than any in the past century at 230,000 deaths, and among the worst natural disasters in recorded history. The Island of Sumatra, specifically the region of Aceh, is the hardest hit region. "Before the 2004 tsunami in the Indian Ocean, architects had hardly figured in the task of post-disaster aid. It quickly became clear that the skills of architects were not being employed" (Harris, 2010). Thus, this research aims to emphasize the role of architecture in disaster relief efforts by providing a resilient structural framework.

The 2004 Indian Ocean tsunami mentioned above, besides being the largest of its kind in recent history, presented a prime case for study. The impact area was of island nations where their lives centered on the proximity of water in significant ways. The time frame since the tsunami also allows for study of all presented relief structures, temporary, transitional, and permanent, for success and shortcomings. Of more recent occurrence is the repeated devastation to Haiti. Haiti is the poorest country in the Western Hemisphere and constantly faces adversity based on its tropical location that consistently puts it in the path of hurricanes and other tropical disturbances.

In 2010 Haiti was dealt a devastating blow as a magnitude 7.0 earthquake occurred with an epicenter only 16 miles from its capital and most populous city, Port-au-Prince. The Haitian government estimated 316,000 died and over 1,000,000 were made homeless by the earthquake (Fig. 1). A cycle of inadequate shelters is perpetuated and exacerbates loss of life in further comparatively mild disasters. Shelters that should have been temporary accommodations were damaged by Hurricanes Issac and Sandy in 2012.



Fig. 1 Haiti during Hurricane Sandy 2012 showing the typical level of flooding in even a minor hurricane (Photo: Swoan Parker/Reuters)

This research effort seeks to design a series of modular structures, a framework kit, for constructing dwellings in tsunami, hurricane and flood prone areas of impoverished countries. The “kit” would provide a method of creating a dwelling that can be arranged in various configurations though common connectors to provide the basic functions, enclosure, roof, floor, as well as being transitioned into long-term, permanent structures with structural integrity that will bring the country design practice up to a better standard.

This kit will produce dwellings that are of a transitional nature to start. Transitional architecture being defined as structures meant for occupation a period of two to three years, but also usable as a foundation for a permanent dwelling. “An important strategy for speeding reconstruction has been to design and build transitional housing using materials that can be repurposed for the construction of permanent housing.” [3]. Transitional structures are not of a disposable nature (thus more sustainable), safer under climactic conditions, and capable of being responsive and adaptable to the cultural context. It has also been shown that “transitional” may be a misnomer, since many people never leave these homes, nor are the homes upgraded. Wherein the issue of a shelter solution, it is a prescribed and insensitive one, as many emergency shelters currently, providing no input or materials from the users as well as lack of consideration for the local climatic conditions.

This study focuses on designing within the needs and demands for safety (prevent loss of life and properties), affordability (through economies of scale and modern techniques) and the flexibility to accept the vernacular methods of construction and materials at hand for a complete structural solution.

Adaptability will be shown to accommodate a more culturally and economically responsible solution. If the sole aim is to provide shelter, you’ve provided a solution for life, but neglected a solution for living. Therefore a more holistic approach will be taken than providing a shelter being the sole aim. A solution that may be overbuilt (inefficient) but has flexibility is preferable.

Initial cost of the structure will not be an issue, though thoughtful response as effective management is necessary to not “waste” money. “The plight of the affected people and countries prompted a worldwide humanitarian response. In all, the worldwide community donated more than \$14 billion (2004 U.S. dollars) in humanitarian aid.” [4] As an example, the Sri Lankan government established a \$600 per unit cost under its shelter policy for both labor and materials. Furthermore, the proposed design solutions though slightly more costly at onset, are actually more cost effective in long terms because of their long lasting, and better suited to the local conditions.

Also through providing an adaptable and expandable solution (Fig. 2), a minimized cost will come in comparison to solutions that have might be deemed as wasteful or inappropriate. The estimated cost will also be weighed against the benefits it presents over an inflexible precedent solution.



Fig. 2 Folding relief shelter for Grenada (polymer coated cardboard)

## II. BACKGROUND

### A. Role of Architecture

The body of architectural works involved in solely emergency shelter design is minimal, but comes from a rich history of prefabricated and modular architecture. These architectures arose from a need to erect homes quickly around the wartime era. Speed of erection, durability and numerous other concerns of which directly correlate to disaster relief are primary concerns. Given that the first responders to disasters, even now in our modern age of travel, are military units, it is no surprise that there is a connection to military barracks for wartime troops. The World Wars also produced massive amounts of displaced people across Europe and resulted in huge immediate demands on housing. The US Federal Public Housing Authority after World War II sent 30,000 prefabricated homes to England in response to the need.

In addition, earlier in this century many countries underwent large changes in its housing needs and great demands were placed on housing. Many of the most well-known architects produced responses to this need. One such architect was Buckminster “Bucky” Fuller [5] who had an immense fascination with the ability of modern fabrication to produce structures quickly and with the most efficient forms. He viewed housing as being an archaic trade that was not making use of the recent advancements in materials and technologies. These lead to his most iconic contribution to even the common lexicon, “Bucky Balls”, the geodesic dome. Other experiments went into his Dymaxion [5] dwellings which were an important experiment. His “Dymaxion Houses” were his attempts to maximize efficiency of space, materials, and all systems in the home.

Another prominent architect, Walter Gropius, after fleeing Nazi Germany, was heavily involved in a transportable system, highlighted in his Packaged Housing System an extension of his prewar works like the Copper Houses made with Hirsch Copper and Brass Works. The packaged house system employed a connector system in the corner joint to connect a shell formed from panels. This system and many others built around the time were all failures. The cost to produce off-site with transportation made them economically unviable in comparison to what has become the typical model of building on site suburban communities. So if a simple supposition of the architecture being valid, one either needs to reduce cost at off-site fabrication or minimize transportation costs by designing to an optimum density for transportation.

### B. Modularity vs. Prefabrication

There are two subjects within the topic of transportable structure, modularity and prefabrication. The two are often entwined but neither is dependent on the other for their existence. Modularity defines the methods of connection, regardless of scale, whereas prefabrication speaks to the amount of assembly accomplished before it reaches the site.

Fuller for example, while he did modular work (the geodesic dome [5]), was greatly interested in prefabrication. He was deeply fascinated with the ability of large machinery to lift large assembled structures whole. In his Dymaxion dwellings he imagined cranes being able to lift entire levels up to their installation. In his most noteworthy creation, geodesic domes, with partnership with the armed forces he would build these structures whole and have helicopters deliver them from aircraft carriers to their site. He envisioned helicopters as the new delivery fleet for his structures. While helicopters deliveries are greatly used in aid work due to their ability to land and take off vertically from constricted sites, labor in developing countries is cheap. Prefabrication should only be used where it either improves survivability of further disasters or comes where the skilled labor is not present or feasible to teach.

Modularity, speaking to the connections, has been explored at a multitude of scales, from the micro-connection to how one unit might attach to another unit. For example, Jones Partners of Los Angeles has done a large amount of work in the field of ISO container use for architecture. ISO containers are a standardized unit recognized across the world and in over abundance.

They have developed a system, called PROcon, that utilizes the entire ISO container as a macro module, but the modularity also extends to the micro-scale of how the units assemble in predetermined ways to form their larger composite structures.

Another precedent of note for this research project is the Cellophane House produced by Kieran Timberlake [6]. In their body of research, parts are designed to be upgradable and usable in multiple configurations. It was designed and produced for the MoMA Home Delivery exhibit, an exhibition of the history of prefabrication and homage to the return of full scale structural installations to the museum. The Cellophane House is primarily modular components but was mostly prefabricated, though it could be built without prefabrication (Fig. 3). That means it can be also constructed on site in case of availability of cheap labor [7].

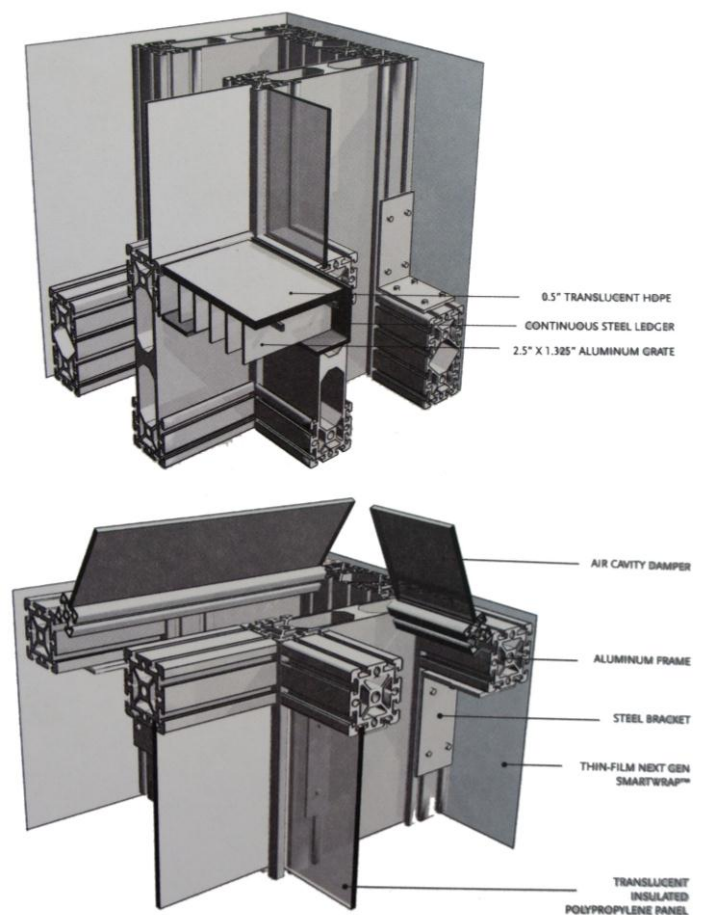


Fig. 3 Cellophane house

### C. Disaster Relief

Until recently the literature in Architecture has not addressed disaster relief shelters in great detail. The recent highlight of it is in large part due to the increasingly connected world we are in with media coverage of disasters. With coverage being nearly immediate the plight and concern brings large actions. The media coverage certainly has brought a large awareness, but the flood of aid money has also brought an increased scrutiny of the aid use. Donators would like to see that their money is being used wisely and in pursuit of a story, the media will highlight the conditions that are inadequate whether they are a sole symptom of the emergency architecture or not.

As shown in *Beyond Shelter* [1] the plight of displaced people are rarely caused in whole by inadequate consideration of architecture, but are exacerbated by an architecture that does not understand or address the conditions that caused the plight in the first place. Davis details that due in large part to the rapid urbanization of the developing world, conditions are ripe for disaster and often feed a vicious cycle. The recent earthquake in Haiti highlighted this with the large amount of damage and deaths resulting from structures that were inadequate before the earthquake. Then afterwards, shelters that by their temporary or transitional nature structurally inadequate, are placed in the same poorly sited places causing further complications of health and safety.

NGO's like Oxfam [1] go into great details on the necessity of an involved designer and a transitional structure. They do not address exact methods of construction because these methods rely primarily on learning the culture that the shelters are to be placed in, for more effective construction procedures. The flaw in this is the lack of immediacy of the solution. The

response time of the need to a shelter was measured in years despite the basic components of shelters being similar across cultures.



Fig. 4 UberShelter

In the literature few of the solutions address adaptability to site. The solutions are so generic that they fail in one of the aspects that have been addressed as goals for this project. If they succeed in being well adapted to climate and the cultural needs/materiality they do not succeed in speed or adaptability, the shelter can't be applied elsewhere, etc...

In the precedent of relief work, one could classify the precedents into two categories: a solely provided materials and one that attempts to use the locally available materials. Both have benefits and detractions. For example, a shelter shipped solely with provided materials does not need to rely on the possibly spotty materials available and can readily guarantee the level of security and safety. A shelter, however, that uses natively found materials eliminates the need for shipping and gains a means for repair that is unlikely with a provided material. This research attempts to bridge and hybridize the two.

A precedent of note that was examined in depth is the UberShelter, depicted in Fig. 4 above. The system suggested in this study closely mirrors the UberShelter design in materials. It uses structural steel frame system where the designer has done an in-depth structural analysis and design checks against extremes loads. Given its outward parallels it will serve as the benchmark for this study.

Recently, a joint effort of Habitat for Humanity and Architecture for Humanity produced a recent report on the transitional structures produced in Haiti in the aftermath of the 2010 earthquake. They evaluated without bias the entire in place shelters used and provide a methodology and prioritization of upgrades to make the shelters a permanent housing. They approached the subject after the structure was in place, but the evaluation is sound for anytime. This study is key for its ideas for moving from transitional to permanent structures and its documented work of current Haitian shelters in use since the 2010 earthquake.

#### *D. Site Conditions*

A primary and often obvious issue is the site and climate issues inherent in the shelters. Architectural issues are inescapable from this. There are always orientation issues in relation to shading and each climate necessitates an architectural and structural response.

The final site example in this research will be the island nation of Haiti. This is the primary site for this investigation and thus more in-depth evaluation is provided. As stated previously the state suffers chronic devastation due to hurricanes and seismic activities (Fig. 5). The nation is being considered as the poorest country in the western Hemisphere. It provides a close geographical location to the US and a prime example for the need of designs that last and are safe in the face of a constant possibility of disaster.

Haiti has a near constant hot and humid tropical climate. It maintains a two-season system of a wet and dry season. The conditions of an extended wet season have been exacerbated by a massive amount of deforestation that has occurred since the 1800's and its colonization. This deforestation has led to an increase in poor sanitation because of an inconsistent water supply



due to soil erosion and an underdeveloped infrastructure. Infrastructure is outside of the scope of the architecture, but soil erosion does pose an issue for the permanent siting of designs and how to responsibly deal with the water drainage of a built structure. Therefore, part of the design concerns would be solid anchoring, possibly with topography accommodation. Though the study is aimed at the flexibility of design, a hot humid climate is an indicative choice of most disaster needs and designs for cold climates will be considered in a separate study.



Fig. 5 Hurricanes history that passed near the capital (Photo: NOAA)

Haiti that suffered a massive blow in the 2010 earthquake also finds itself in the path of hurricanes quite often. Thus, this study will consider resistance to seismic, wind and water (rain not storm surge) events (Fig. 6). While surviving a full blown disaster after the initial event while still being in a transitional phase is a problematic proposition, but in the path to permanence the faults that made the disaster as severe as demanding a new architecture and engineering, solutions need be addressed [8-10].

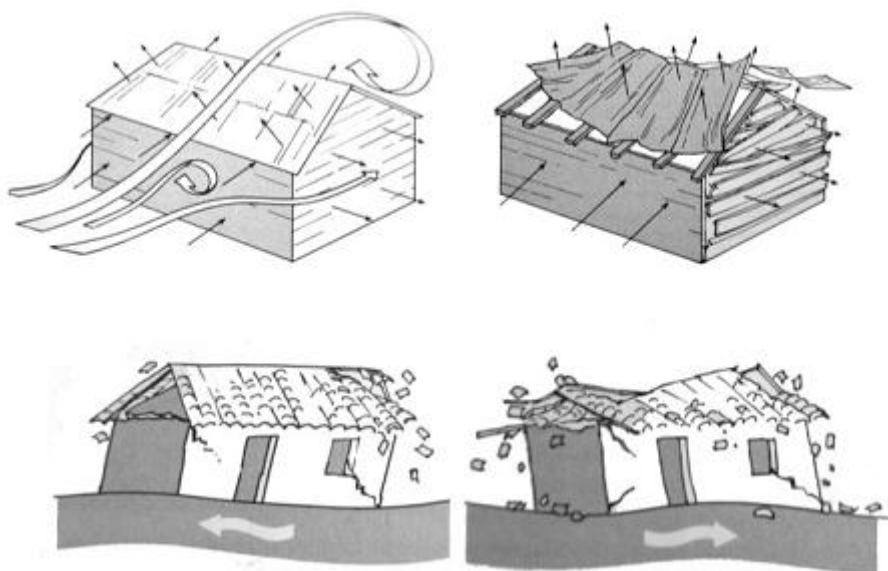


Fig. 6 Typical hurricane and seismic building damages

### E. Social Issues

An often overlooked aspect of relief work is the safety in regards to burglary and violence. After a disaster of large magnitude what precious few possessions that people have should be adequately secured to prevent other opportunistic displaced people from taking them. IDP camps are not immune from violence such as rapes and beatings, openings should be secured in ways that prevent this if possible.

Not all refugees are of short inflicted disasters that are environmentally driven. War and economic refugees abound in areas such as Africa. Localized violence in conjunction with political upheaval or famine creates rapid movements of people that stress resources and invite security concerns. Sometimes the fighting that displaces people comes with the refugees.

Emergency shelters, largely tent structures with plastic fabrics, cannot address these social issues. The structure level this study intends to start at is a transitional structure that is more stable and secure which will promote more ownership, an important role for it to become a permanent solution. This approach will address many of the social problems mentioned earlier more efficiently than the current emergency shelter practices. At the heart of this design approach is the ability to adapt to various conditions and needs as time passes, a scalability of design. Needs are not all alike for each individual, why should their shelter be the same? Trade, family unit size, culture and numerous other factors lend themselves to different typologies: One-room, one-room with storage, two-room, one-room with porch, etc... This research will seek to show how the framework system can accommodate these different configuration needs.

### III. DESIGN STRATEGIES

The principal design strategy for the disaster relief is a structural framework that provides the flexibility to grow, improve and respond to site-specific requirements. With that level of flexibility and consideration to the program requirements of daily life the design strategy emphasizes also a path to a permanent solution. More specifically, the design strategies include:

- Ability to expand the plan beyond the initial floor plan in the provided shelter.
- Being able to accept numerous, though not necessarily unlimited, types of exterior cladding.
- Limiting the amount of on-site fabrication and cutting of the structural elements if possible to no cutting required, so that there are limited or no special tools needed to build the structure.
- Ability to survive future disasters. It has been shown that [2] that the duration of peoples being displaced is increasing. A major factor in this increase is recurrence of minor disasters. If quality shelters are not provided, the occupants in the same or worse situation would be left as the primary disaster.

For the continuation of the design and satisfying the strategies outline above, this study utilizes a readily commercially available system of structural hollow steel section (HSS, A992) that readily sleeves into each of its available size variations. Details of this will be explored in the next sections (Figs. 7 and 9b).

One design change taken to the available HSS was specifying a series of perforations along the length of the framework. This serves as a modular system of attachment for cladding. With this setup there was a back and forth between the typologies determined as ones vital to the rebuilding of a community and the connection types needed. The typology needs to determine the connections and how to expand the collection of “parts” in the kit.

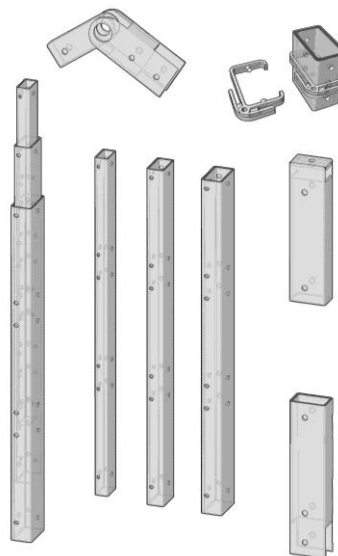


Fig. 7 HSS system proposed

### IV. DESIGN DETAILS

#### A. Connections

The connection types are designated using either the larger or smaller sizes in the available HSS. These then use the pre-drilled holes as moment connections to attach the tubes whether inside or outside the main tubing.

This set of connections is a trade-off in special tools. As is, the assumption is that a nut and bolt connection would be required and a wrench or socket tool to secure along with simple instruction sheets illustration the connection process. This would be provided. Further exploration could go into a rivet type connection that would be put in place with a hammer only, as hammers can be assumed to be a “common” tool readily available or provided in relief supplies before the transitional stage. Connections like Grip Clips would do for tarp connections to the structural frame.

The suggested connection types are as follows (see Fig. 8):

- 1) Over Sleeve
  - A) Tongue and Groove (orthogonal joints)
  - B) Butt Joint (orthogonal joints)
  - C) Rotating Joint (trusses and roof ridge)
  - D) Extension (increasing span length)
  - E) Perpendicular Rotating (trusses and roof creation)
- 2) Inner Sleeve
  - A) Rotating joint
- 3) Perforated Panel Attachment
- 4) Lateral Bracing

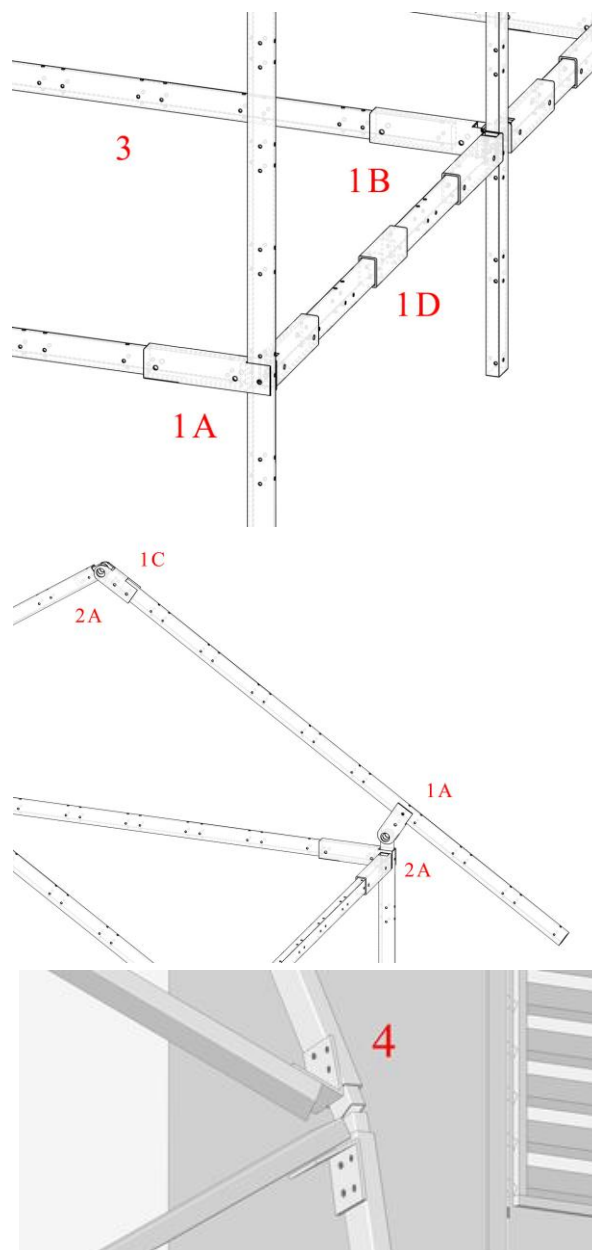


Fig. 8 Types of connections



### B. Member Sizes

After structural analysis computations according to ASCE-7, 2005 and structural steel design using AISC-2005 codes were conducted, the main tubular members selected are 3.0m and 1.0m in length and cross-section varies from 152.4 x 50.8 x 9.5 mm to 01.6 x 50.8 x 3.2 mm (SI units were used for these units because they will mostly be designed in countries that adopt metric units). The lengths are optimized to minimize any cutting to the tubes and standardize the connections for flexibility, but also meet shipping concerns. A key necessary component of disaster relief for provided shelters is transportation (how tightly can it fit and for what weight). Also the exterior cladding can then be standardized at 1.0m in width, fitting on pallets perpendicular to the 3m tubes and also needing no cuts on site. This standardizes openings and expansions to either the 3m or 1m increments.

The construction kit uses the maximum size of the roofing panels to determine the footprint of the “Flat pack” parts, then it uses an inventory of the parts and the height was determined by stacking the footprint (see Fig. 9a).

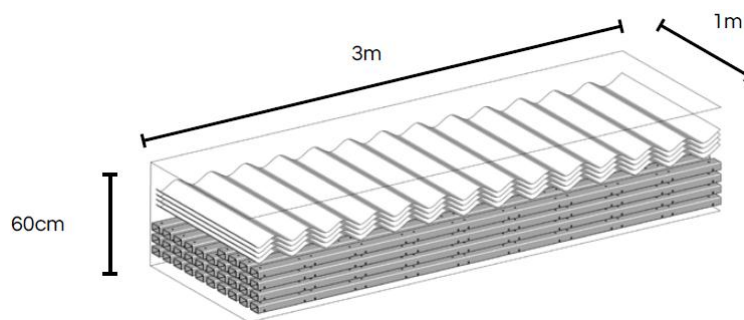


Fig. 9a Flat Pack Dimension

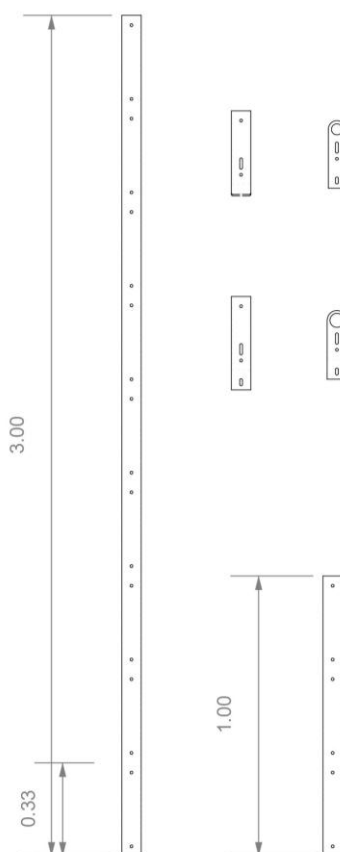


Fig. 9b HSS with holes marked

- |                            |           |
|----------------------------|-----------|
| 1) 3m Hollow Section Steel | 28 pieces |
| 2) 1m Hollow Section Steel | 11 pieces |
| 3) Over Sleeves            |           |
| A) Tongue & Groove         | 16 pieces |
| B) Butt                    | 22 pieces |
| C) Rotating                | 9 pieces  |

- |                           |           |
|---------------------------|-----------|
| 4) Inner Sleeves          | 9 pieces  |
| 5) 3m x 1m Roofing Panels | 12 pieces |

The proposed design of the framework consists primarily of the 3m x 3m bay structure and where the needed 1m interval was inserted. The 1m tubing is used mainly for cladding attachment and similar architectural elements and concerns. The 3m HSS becomes the primary structural elements (Fig. 10).

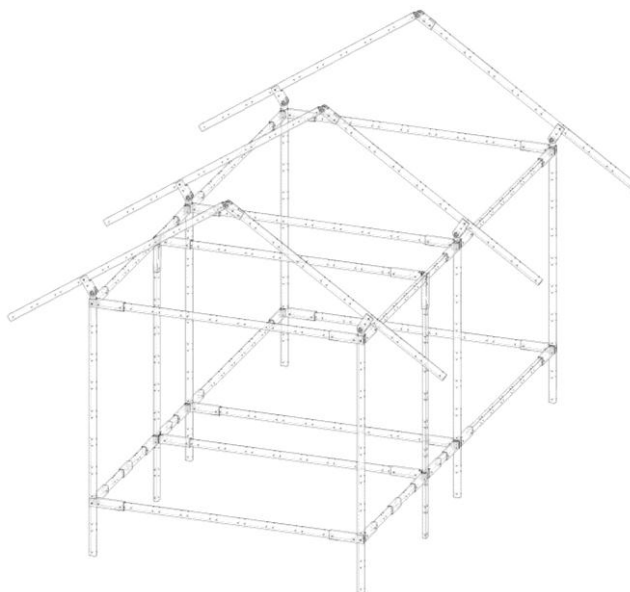


Fig. 10 Trimetric View of the Kit Frame

As mentioned previously, the only additional work to be rendered on main structural tubing from the stock tubing is a series of perforation, holes placed at 33cm intervals down the length of the tubes. These holes become the attachment points for all structural and architectural elements (e.g. joints and claddings). The joint shown at Fig. 11, a corner roof joint, exemplifies the means by which the multiple sizes of tubing can nest within each other and be bolted.

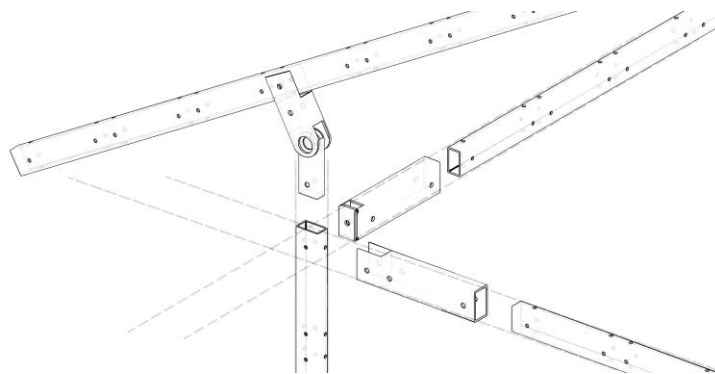


Fig. 11 Connections at a typical roof joint

### C. Typology

Four typologies are recognized and perceived as necessities for the returning of a community back to its pre-disaster life. These typologies are as follows:

- 1) Single Typology
- 2) Double Typology
- 3) Workshop
- 4) Community

#### 1) Single Typology

A single room typology is the base possibility for a living structure. It provides the minimum of coverage and space for a substance living (3m x 4m). It would be a single room with a porch. As shown below in the images and others throughout this document, it is shown that this is the typical configuration for the single family dwelling (Fig. 12). The typology also matches the USAID [8] space requirements closely. USAID sizes are approximately 5m in depth and 3m in width.



Fig. 12 Trimetric view of single typology

The single room typology is typical of the vernacular and the relief work, but it is inadequate for improving the conditions of the people or the only needed structure (a failing of IDP camps). It doesn't include storage, water, cooking, and others that are necessary components of life (Fig. 13).



Fig. 13 Example of Haitians modified shelter [2]

## 2) Double Typology

A double room typology is an expansion of the single room type. As the structure strengthens in its exterior cladding, it is purposed that the footprint would also expand as needed to fit the individual (Fig. 14). This expansion of course will depend on the site conditions and availability of space. Either renewed resources over time allow expansion or the taking down of other single room structures provide the materials for this typology. Care would be taken by the designers to make sure typical cramped IDP camp conditions are not perpetuated, allowing the structures to expand. The social needs for expansion might be numerous too: a larger family, cultural norms, etc... Additional keys are the possibility of storage and other life giving systems like water. In most relief work for shelter, they do not consider for example where or how a person would cook. If in a rainy climate the cooking area isn't sheltered you've put an extreme hardship on the occupants.

Many possibilities for expansion are explored in the next pages. The expansions are not limited to these possibilities though, as is the point of the flexibilities of the connections available. As need and opportunity meet the expansion possibilities that are still available.

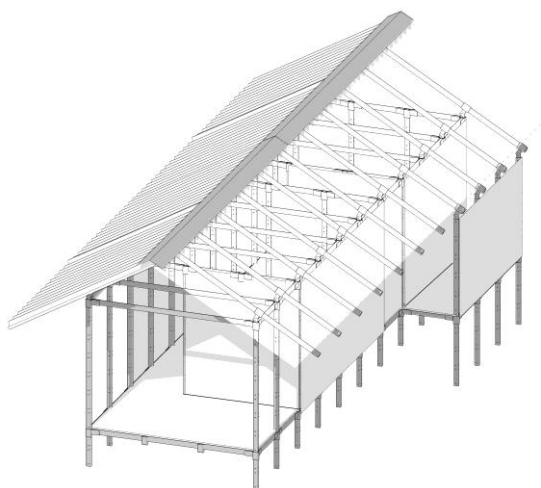


Fig. 14 Double typology

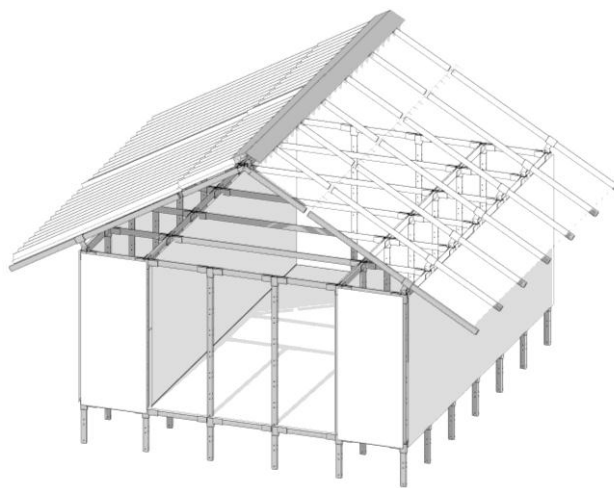


Fig. 15 Workshop

### 3) Workshop

Returning to a normal life includes the aspects of commerce. While many live a subsistence lifestyle, commerce is becoming a key aspect to the return to normal life activities. This typology is presented as a part of the options for a cottage industry producing parts for this system and an introduction to other means of financial support through small business (Fig. 15).

Personal experience of the authors and surveys of many burgeoning third world economies would show a need for these larger than single typologies that aren't meant for living. Of primary concern is the adequate space for presentation of goods, but also being able to secure them against rampant thievery and weather.

The typology depicted above shows a footprint expanded in width by 1m to each side. As the porch eliminated the working floor is as large as the single footprint. For storage of goods and tools the 1m side expansions would be the only clad portions of the example, lockable and closed. Since the livability of the structure is not a concern, a typically insensitive cladding like un-insulated metal panels can be used to provide a secure shell for protection of goods and tools.

### 4) Community

In disaster relief there is always a need for a "large" sized typology. Communities on maps of countries like Haiti are designated by churches or schools, in fact the largest structures. Thus, it would only make sense that these important markers of a community would need to be restored to facilitate a return to their pre-disaster way of life.

A "Community Center" would be used as the largest multi-purpose part of the plan. There is a need for distribution and storage of resources after a disaster such as clean water and food distribution. Other international aid organizations like Heifer International are giving animals to raise as a part of a sustainable approach to aid. These animals can be also sheltered in these centers. Also the centers can serve as a planning center as other aspects of this plan is developed for the specifics of the community and site (Fig. 16). Community trust is garnered with the first building and experienced gained in the more complicated construction that makes the smaller typologies' construction easier serving as the model to "sell" locals on the advantages of the structure that may seem "foreign" to their typical vernacular materials.

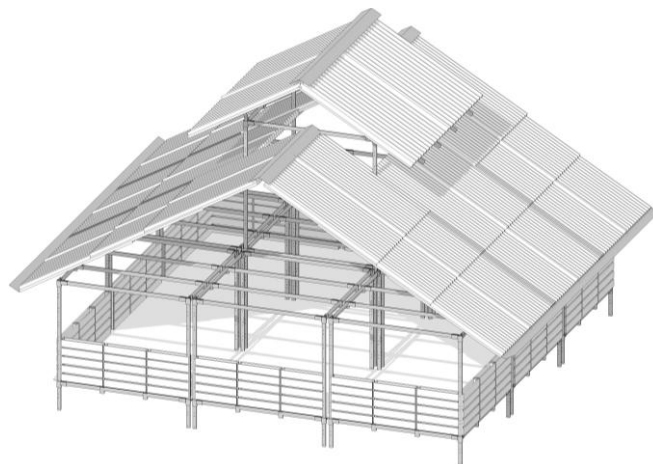


Fig. 16 Community typology

The 3m x 3m module of the community design revealed the methods with which would best be used for expanding the shelters to a larger size including vertical progression (Fig. 17). The current modules can support up to two floors. However, expansion to three floors can be achieved with simple size changing to the basic elements.

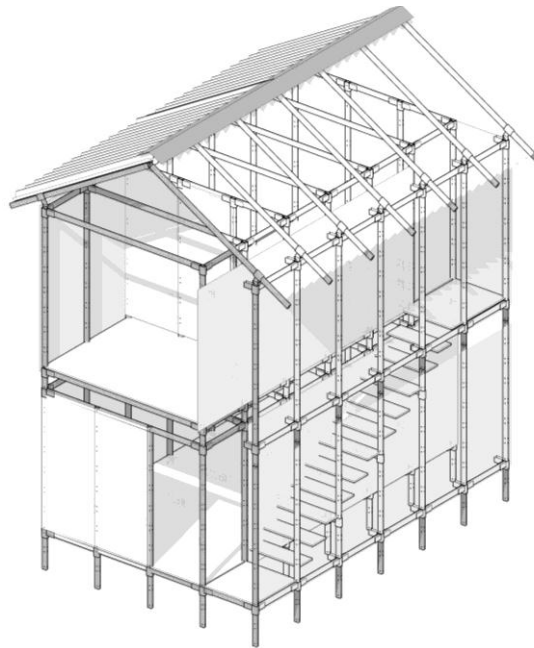


Fig. 17 Vertical expansion

Similar to the community typology, other typologies can be achieved to suit various terrain and program requirements (see Figs. 18 and 19). Arraying the basic module in different ways allows adaptations to various site constraints and turn corners making non-rectangular designs (Fig. 19).

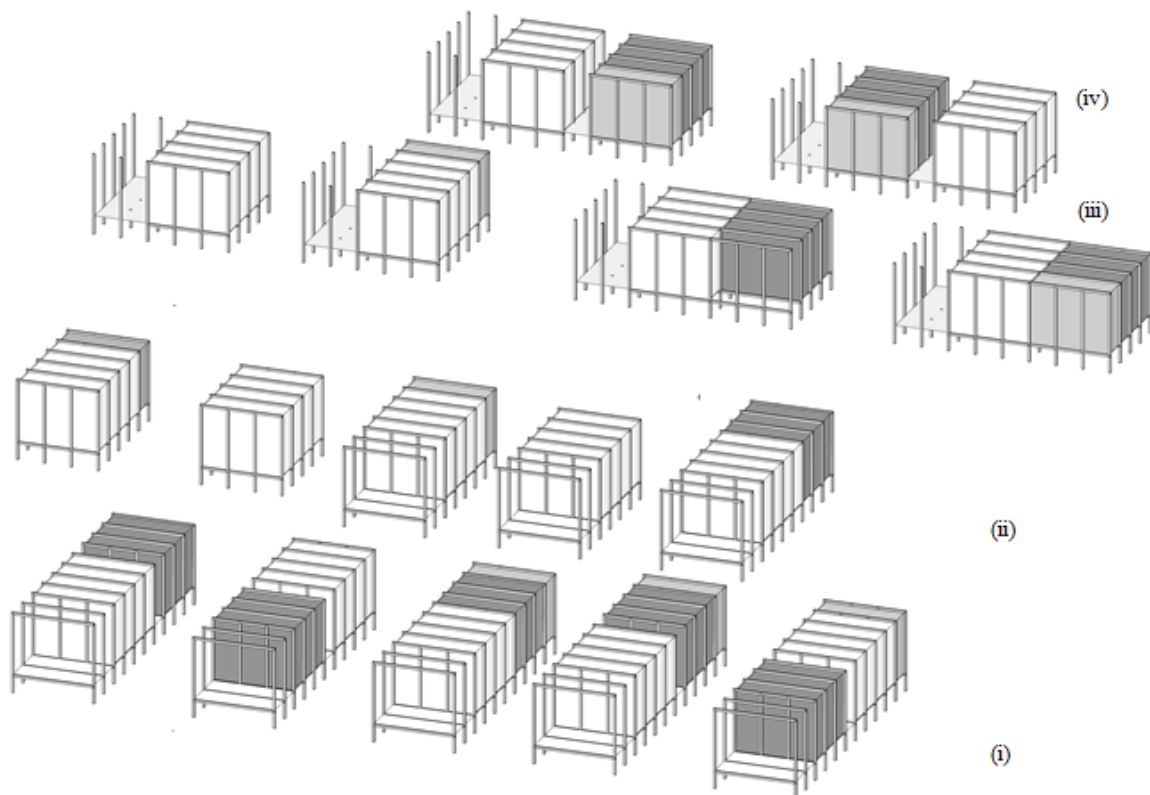


Fig. 18 Expansion Variants: (i) Porch - The default single configuration are shown with a porch as it is such integral way of life for many cultures, social and physically. Thus, the assumption is made it would be built at the initial stages. The addition is 3m x 2m. (ii) Second Room - The second room configuration can be of any use the occupant sees necessary. (iii) Storage - This 3m x 1m addition is stated as storage but is for a non-living portion and its size reflects that. (iv) Breezeway - This breezeway for example could be a break in the living area that separates the kitchen area, or from a sleeping area to make a cooler and more comfortable environment



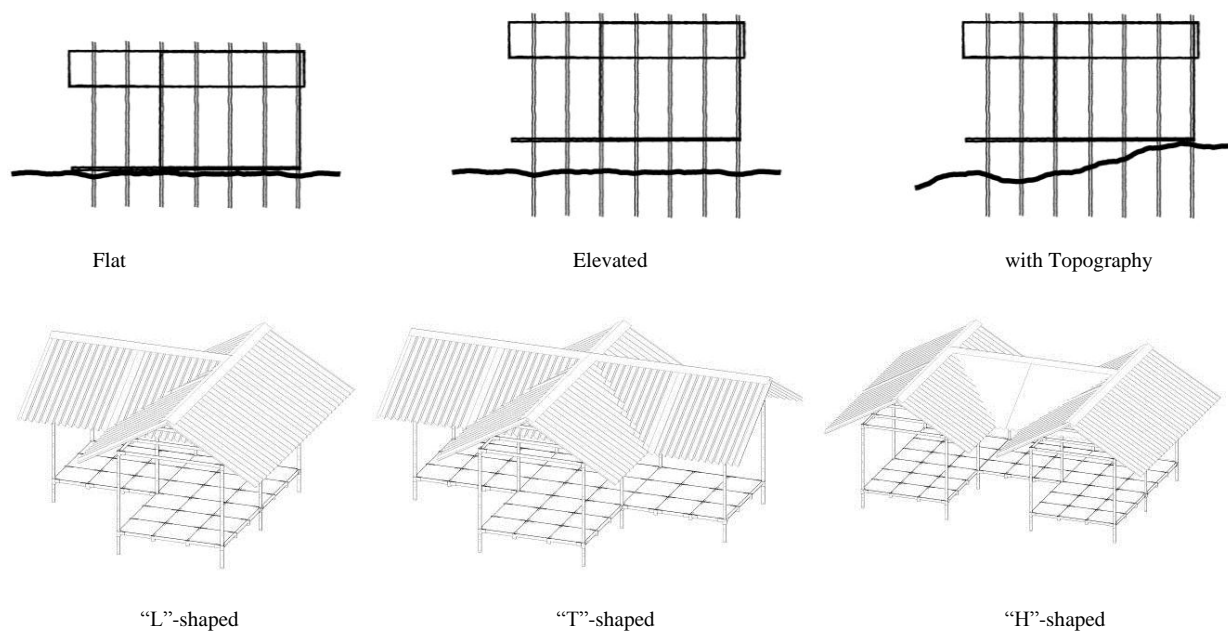


Fig. 19 Typology for various elevations and corners

#### V. TRANSITIONAL TO PERMANENT

This section examines the shelters and detailed ways to extend the lifespan of the shelters beyond their initial design. In this study the following phases of disaster relief are considered:

- A. Transitional (months to 2 years) - A shelter that uses materials that can be reused or adapted for better shelters. In the case of this study the design is the framework with the reusing of tarps. It remains vulnerable to crime and intense weather but provides better shelter than the often tent-like emergency shelters.
- B. Semi-permanent (2-5 years) - These shelters can be any combination of strengthening the structure of the shelter or improved materials more adapted to the climate and security needs.
- C. Permanent (5+ years) - A dwelling that would no longer need any material or design input to be a livable dwelling, excluding maintenance, and would survive all but the most extreme disasters.

##### A. Transitional

While “transitional” shelter has been the cornerstone of disaster relief work, the name itself has proven to be misleading. The occupant is intended to move to a permanent shelter or improve the transitional shelter to become a permanent one. Often neither has been shown to be true as they stay far longer than the shelter was designed or adequate for.

Of the two options for how to move on from transitional shelter, fortifying the shelter to a permanent one is the most applicable one to this research. Since flexibility of material use is already a goal the typical nature of these shelters can be accommodated by the system.

The transitional version of this shelter would be the basic structural framework and roofing. The exterior cladding would be tarps repurposed from the emergency shelters and easily available after disasters (Fig. 20). This provides for the most compact of possible shipping sizes.



Fig. 20 Plastic tarps as cladding for shelters

### B. Semi-permanent

The semi-permanent configuration of the design represents a fortification of the transitional design. The exterior of the shelter can be constructed using wood (see Fig. 21). This example assumes that the pallets with which it was shipped are available for the cladding or from other shipments of relief aid. This possibility eliminates the problem of places that are deforested, like Haiti, where wood is not readily available.

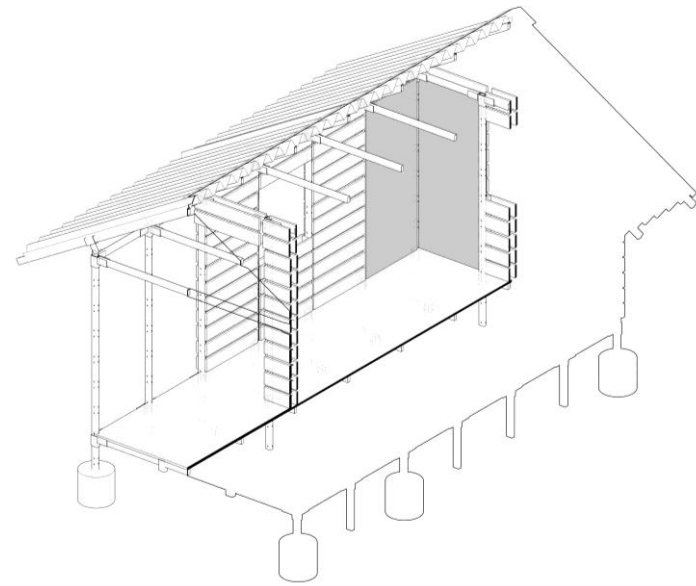


Fig. 21 Semi-permanent module of the framework

The cladding serves as protection and better adaption to the climate, but more importantly, this version is shown as more fortified against weather and future disasters. The example depicted in Fig. 21 above uses footings that could be cast concrete in 5 gallon buckets (readily available) and shear panels placed at the corners. Footings would help against land moving events and the panels against lateral forces produced by earthquakes or hurricanes. The panels also represent the idea of readymade panels being prefabricated and shipped later than the initial structural framework. SIP panels are precedent materials for disaster relief, but they do not represent an efficient way to ship a shelter as by their nature they must be completed before shipping, causing expense and inefficiency for their weight to maximize deliverable shelters.

### C. Permanent

The permanent module of the designs presents a further fortification (Fig. 22). For example, Fig. 23 illustrates the application of CMU as cladding material, which in part due to the 1m module fits 2 1/2 standard bricks, and further fortification with a concrete pad foundation. The weight of the CMU presents an issue for headers, but the system can accommodate this by attaching a 1m tube as a support below the headers and using the system as a method.



Fig. 22 Haitian example of CMU/captive masonry construction

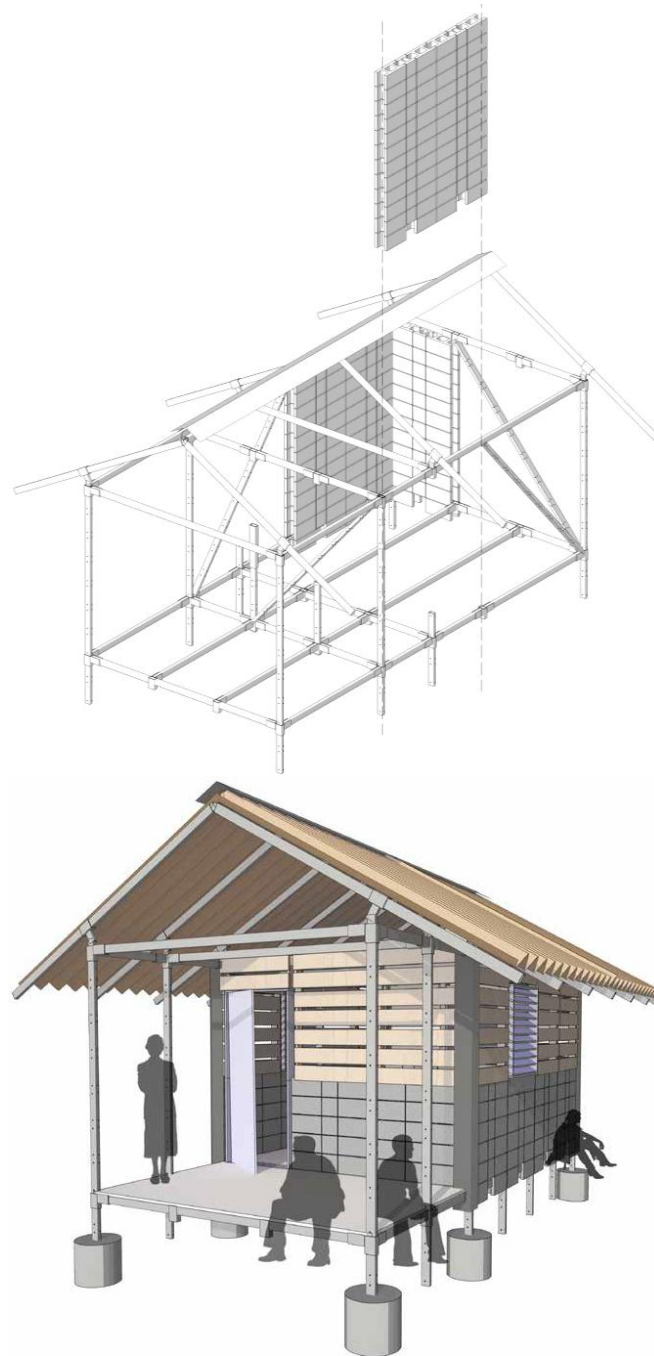


Fig. 23 Permanent module

This type of iteration of the design would be another possibility for areas like Haiti where wood is not readily available. With the workshop prototype it is feasible that molds for CMU bricks could be manufactured by the community and brings about their own transition to permanent shelters by means of non-relief-based aid.

Another variation of the permanent module is depicted in Fig. 24. The form of the semi-circle is the strongest against wind forces, which therefore drives the form. Subsequently this design is more heavily involved in the roof paneling. This is a trade-off for the increased wind resistance to survive wind storm events like a hurricane.

The amount of materials to build in comparison to the increased fortification makes little sense for every typology. Extreme wind events are rare occurrences and hopefully by the time another wind event occurs the structure will be built out to permanence (and thus more wind resistant) before such reoccurrences. It is also more difficult to expand upon for flexibility. Therefore this typology would be best used for community essentials in the event of disaster reoccurrence, like food supplies or water purification systems that would be vital in the immediate aftermath.



Fig. 24 Permanent module: nonlinear version

## VI. CONCLUSIONS

Millions of people have been affected by natural disasters and hazards in the last decades. Disaster Relief in these areas has been traditionally focused only on the realm of temporary structure. This approach has not been proven to be ineffective in most cases due to the fact that people never leave these temporary homes, nor is their homes upgraded. Such Relief structures have failed to anticipate needs of growth and daily life sustaining activities that go beyond the immediate need of shelters.

This research seeks to provide a solution for disaster relief that addresses a path from a provided temporary structure to a permanent architecture. The proposed framework provides considerations for expansion and needs for clean water, food storage and cooking and other life sustaining functions that go programmatically beyond “shelter”. The framework is based on steel modular structure that provides the flexibility to grow, improve and respond to make a quicker path to normal permanent lifestyle.

The proposed structural framework kit offers a multitude of variations of structures possible by the combination of tubes and connections. The limitation on design permutations is a limit most often encountered in the designer’s mind and not the proposed kit. Through the typologies suggested, most cases observed in relief work for the common structures used are covered or within the means of the suggested system to be built.

Not only does the proposed system allow a multitude of spatial arrangements initially, but also the cladding, structural strength and permanence is shown to be capable of evolving. Without the limits of single room typologies so often seen in relief camps, the proposed framework allows for different typologies that ranges from individual to community level concerns, bringing disaster affected people out of endless cycles of inadequacy to permanent settlements.

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