

Abstract

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On January 12, 2010, Haiti was subjected to an earthquake that measured a magnitude of 7.3 on the Richter scale. The earthquake exposed Haiti's vulnerabilities in regards to its built environment, and had a devastating effect on economic and social balance in the region. Although the earthquake created an unhealthy and dangerous environment, it affords the opportunity for Haiti to rebuild with better building standards, improving living conditions and strengthening communities. This thesis will use Haiti as a case study for a designing a system for strengthening communities in regions that fall victim to natural disasters. A prefabrication system will be investigated with the goals of creating a design that will be viable in regards to vernacular construction techniques, delivery methods through rough conditions, providing jobs for locals, and creating a structure that responds to future natural disasters. This system will be implemented with the design of a community center, acting as the cornerstone for developing permanent neighborhoods.

DISASTER RELIEF: A SYSTEM FOR RECOVERY

By

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Introduction:

The inception of this thesis was the practical application of prefabrication. Previous studio work and readings incited thoughts regarding the opportunities of prefabrication and inspired further understanding of its application. Chapters one through four of this document will discuss prefabrication history, theory, and case studies. The purpose of these chapters is to attain a good base knowledge of prefabrication in order to enable the application of its principles to solve a social and architectural problem.

Chapters five through nineteen will investigate the process by which a prefabricated system can be used to respond to natural disasters. The damage caused by the 2010 earthquake in Haiti will be used as a case study for testing this system. The method for making components for easy on-site handling, delivery, and construction will be explored. Additionally, these components will need to be able to withstand seismic activity and wind loads from hurricanes. The end goal of this investigation is the creation of a community center to serve as the cornerstone of developing neighborhoods. This proposal will also explore the programmatic functions needed by regions that are hit by a natural disaster.

Part 1 - Prefabrication

Chapter 1 - Prefab Theory:

Prefabrication is the act of manufacturing raw materials into an element prior to its final application, for the sake of gaining an advantage in the construction process. This is regarded as a relatively new idea. However, a couple of early examples prove that the idea of prefabrication has existed for centuries, yet never evolved into a prominent building technique. As early as 1670 a house was shipped in components from England to Cape Ann in Massachusetts, and during the 1849 Gold Rush, manufactured houses were sent to California from New York¹.

One could argue that houses have always been prefabricated to a certain degree. Door knobs, doors, and windows are usually made by a separate manufacturer and sent prefabricated to the site. When wood is sent to the site, it is usually cut to a certain dimension beforehand. Although dimensional lumber may need additional customization on site, these elements are prefabricated to a specific size to make the construction process easier. The prefabrication process is meant to optimize efficiency, improve quality, reduce cost, and save time. Manufacturers and architects continually try to improve these aspects with more advanced methods of prefabrication².

¹ A.M. Watkins. *The Complete Guide to Factory-Made Houses*. (Chicago: Longman Financial Services Publishing, Inc., 1988), 9.

² Stephen Kieran, and James Timberlake. *Refabricating Architecture : How Manufacturing Methodologies Are Poised to Transform Building Construction*. (New York: McGraw-Hill, 2004), 9.



**Figure 1 It is desirable to achieve better quality and scope for less money and time.
(Kieran and Timberlake, 10).**

In traditional construction methods, the quality and scope of a project are directly proportional to the amount of money and time spent during fabrication. In an ideal world of prefabricated construction, people would receive better quality for a smaller cost; prefabrication has the potential to increase efficiency and quality while reducing the time and cost by method of factory production. Kieran and Timberlake outline this concept through an equation of $Quality \times Scope > Cost \times Time$ (Fig.1).³ Currently, factory construction is around thirty percent faster than conventional construction, and building elements are delivered to the site from the prefabrication factory at about ninety percent complete.⁴

³ Kieran and Timberlake, 10.

⁴ Michelle Kaufmann, and Catherine Remick. *Prefab Green*. 1st ed. (Layton, UT: Gibbs Smith, 2009), 70.

Learning from the Automobile Industry:

Originally, cars were crafted as single entities; unique one-off products. The process of fabrication was very laborious and time consuming, requiring the manufacturers to bring the materials and tools to the location at which the car was being made. Since cars were made up of numerous parts, the process was slow and required skilled manufacturers to assemble all the parts. As a result, cars were being sold at high costs and were perceived as luxury items.⁵

Henry Ford reinvented the construction process for cars with the establishment of the assembly line. Instead of constructing the car in one area, the Model T car was fabricated step by step along a moving line, during which craftsmen would perform the same duty repeatedly at their workstations. This increased efficiency and consistency, allowing for the cars to be mass produced and sold at a lower price⁶. The concept of having the product being made affordable to the workmen fabricating it through means of mass production and higher wages is a term known as “Fordism.”

⁵ Kieran and Timberlake, 85.

⁶ Kieran and Timberlake, 17.



Figure 2 Complex car systems require the parts to be constructed by many different specialized companies. (Kieran and Timberlake, 88).

Since the implementation of the assembly line method in 1908, the different systems in automobiles have progressively become more complex. Consequently, a newer construction methodology was established in the mid-1990s to maximize efficiency in fabrication. Distinct pieces of cars are now being outsourced to other manufacturers who specialize in prefabricating a specific module (Fig. 2). The main manufacturer is the company that owns the name brand of the car, and is referred to as an original equipment manufacturer (OEM). Beginning with the OEM, there may be a few levels of outsourcing from one manufacturer to another supplier, until a part is at its simplest form. The parts will be developed into a “chunk” and sent to the OEM for final steps of fabrication in the form of an assembly line (Fig. 3). The advantage of

outsourcing “chunks” to different suppliers is increased focus on each specific part by a specialist. This creates consistently high quality fabrication, since there is less of a chance that a small detail is overlooked.⁷ Modularization is also advantageous because it mitigates the amount of liability for the OEM. The responsibilities are distributed to the suppliers who are making specific components.

Outsourcing chunks to different suppliers also creates a parallel construction process, allowing work to be done simultaneously. Conventional fabrication follows a linear order of steps, but through parallel construction processes, suppliers can work on different parts at the same time, creating easy assembly of fewer parts in the final stage of construction⁸.

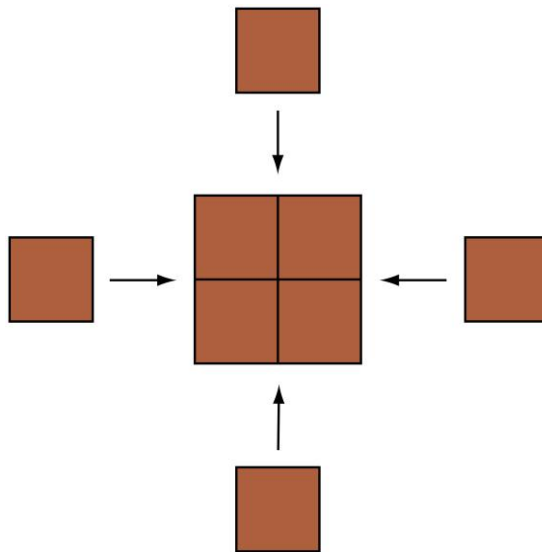


Figure 3 With different suppliers working on modules of a car simultaneously, it creates a parallel process of construction.

⁷ Kieran and Timberlake, 17.

⁸ Kieran and Timberlake, 21.

Learning from the shipping industry:

Shipbuilding traditionally was a linear construction process. The ship would be built on site with an ordered progression, starting with the keel. This prevented simultaneous fabrication of parts. However, similar to the automobile industry, a parallel approach is used in the contemporary construction process.

The construction of a ship takes advantage of modular assembly to create efficiency, save time and reduce costs. The main modules used in ships are called grand blocks. Grand blocks are crafted as large as possible and include all the support systems within each module. Additionally, within each grand block are smaller modules that are prefabricated offsite and delivered to the main factory for installation (Fig. 4). When the grand blocks are completely assembled, they are then sent to the dry dock for assembly within the ship itself. The construction process of having multiple levels of prefabricated modules mitigates the pressure of having one fabricator responsible for the quality of all the pieces.⁹

⁹ Kieran and Timberlake, 73.

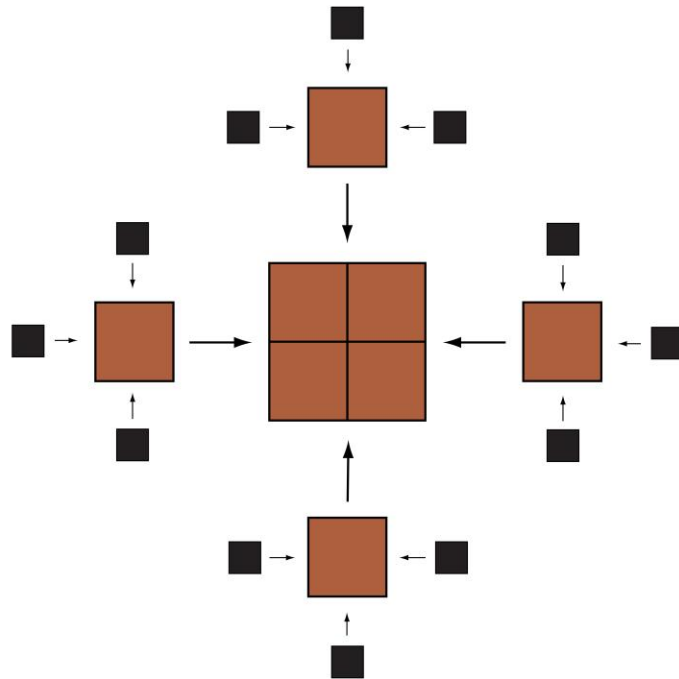


Figure 4 Ships are currently constructed using a series of modules.

Learning from the Airplane industry:

Aircraft are fabricated with the same concept of modularization as automobiles and ships. Similar to cars and ships, aircraft fabrication evolved from a linear to a parallel construction process (Fig. 5). Originally, pieces were sent to the factory and the plane was built up one piece at a time. The current system outsources modules to manufacturers. These manufacturers fabricate modules that integrate many of the smaller parts that were once assembled as an independent element of the airplane. When the suppliers send their finished modules to the assembly factory, the airplane then moves to the location of the parts, similar to an assembly line.¹⁰

¹⁰ Kieran and Timberlake, 79.

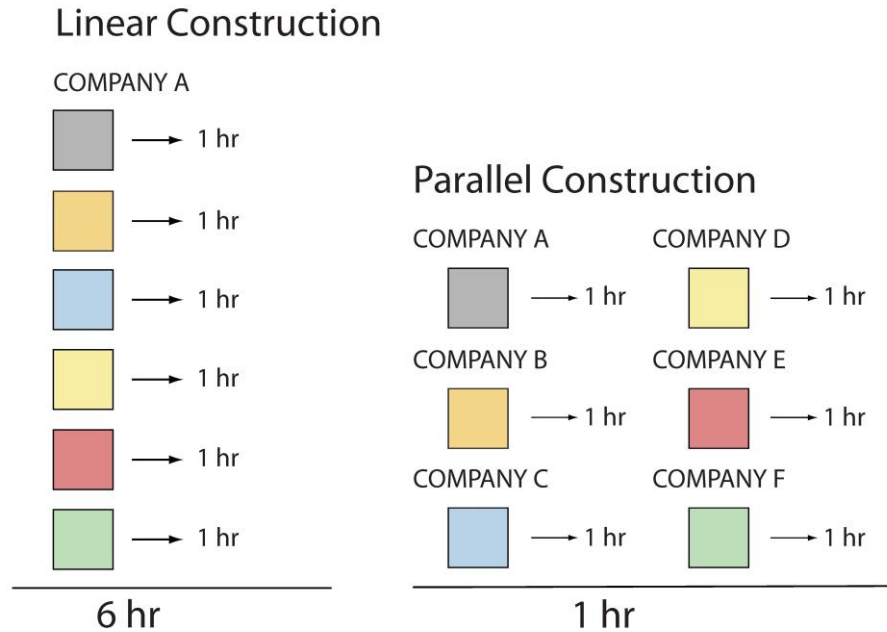


Figure 5 A parallel construction method saves a lot more time than a linear construction method.

The Boeing 777 is an example of module construction (Fig. 6). The aircraft is digitally fabricated using a 3-dimensional model, and then parts are outsourced to over forty manufacturers in many different countries. Cranes working on an X, Y, Z axis continually move modules to precise locations. Lasers are then used for accurate assembly. The use of integrated components saves money because of shorter assembly time; it also makes the aircraft significantly lighter.¹¹

¹¹ Kieran and Timberlake, 81.



Figure 6 The Boeing 777 is fabricated with modules. (Kieran and Timberlake, 80).

Construction of houses:

Cars, boats, and airplanes are complex and mobile vehicles with many specialized components, constructed within a system of modularization. It is surprising that houses, although they are immobile, use construction methods that are less advanced than automobiles, ships, and airplanes. Many houses are still stick built on site, the result of a linear process, and take much longer to complete than a factory built house (Fig. 7).

Factory construction has many advantages. A factory provides a controlled environment that shelters the construction process from the delays and damages potentially caused by weather. Materials are a lot less likely to grow mold or warp in a controlled environment. Other benefits include easy access to tools and safer construction conditions. Modular houses are also built stronger, so they are able to endure traveling conditions in route to

the site.¹² The mass production of prefabricated elements creates efficient use of materials, eliminating the amount of waste from between fifty to seventy-five percent.¹³

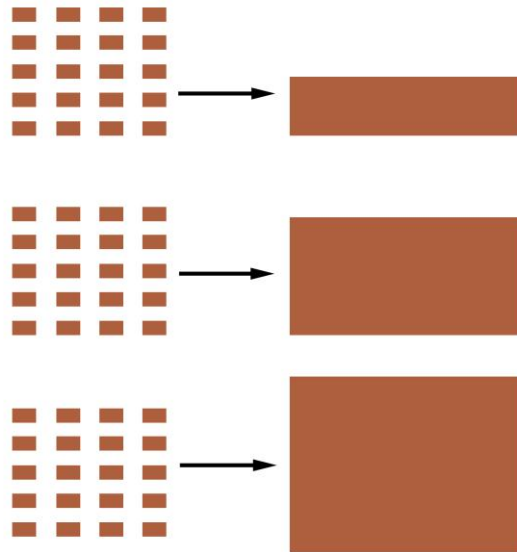


Figure 7 Conventional construction of houses operates in a linear manner.

Integrated Component Assemblies:

The material scientist works on developing new innovative materials, without much collaboration with architects, product engineers, and contractors. This separation stunts the development of producing materials specifically for the sake of improving building systems. While numerous materials have been invented, they have not been incorporated into building fabrication. Innovative composite materials pose the potential

¹² Watkins, 36.

¹³ Kaufmann and Remick, 47.

for higher quality and decreased costs. However, new materials can be riskier to use, since they create a liability due to lack of familiarity.

The role of the materials scientist directly affects the work of a product engineer. The product engineer finds materials that can be used for building manufacturing, and creates integrated component assemblies. The Construction Specification Institute (CSI) is created to categorize properties of the materials available for designers. Product engineers, whose role now includes the development of integrated component assemblies, could encourage the use of integrated component assemblies by architects if they rewrote the CSI so that it informed designers of the whole module instead of individual materials.

A contractor's duty is to purchase materials and manage the assembly of parts. The contractor's role could potentially be more conducive to prefabrication methodologies if supervision extended beyond the scope of individual materials. If a contractor were to manage integrated component assemblies while minimizing on-site assembly, the construction of houses could transform into a process similar to that of a ship or an automobile, where modules are fabricated offsite and sent to the OEM for final assembly.¹⁴ However, the roles played by material scientists and product engineers pose challenges to transforming the role of the contractor. Integrated component assemblies cannot become a prominent fabrication technique without collaboration between the material scientist, the product engineer, the contractor, and the architect.

¹⁴ Kieran and Timberlake, 47.

Prefabrication at the level of the joint:

| Number of Parts | Difference | Surfaces that create opportunities for joints |
|-----------------|------------|---|
| 1 | -1 | 0 |
| 2 | -1 | 1 |
| 4 | 0 | 4 |
| 6 | 1 | 7 |
| 8 | 2 | 10 |
| 10 | 3 | 13 |
| 12 | 5 | 17 |
| 14 | 6 | 20 |
| 16 | 8 | 24 |
| 18 | 9 | 27 |
| 20 | 11 | 31 |

Figure 8 The number of joints increase exponentially relative to the joint.

Advantages of integrated component assemblies are especially important at the scale of the joint, where quality is essential. The joint is important, since it creates a relationship between two parts and becomes an “opportunity for either craft or crisis.”¹⁵ It is important to create a quality joint that can respond to thermal expansion and contraction, shed water, mediate between materials, and permit assembly. Prefabricating integrated components creates the opportunity for well crafted joints, since construction is done in a controlled environment and it reduces the number of parts that need to be joined on site. Kieran Timberlake explains the mathematics behind the logic of reducing the joinery on site; the number of joints increased exponentially relative to the amount of parts (Fig. 8).

¹⁵ Kieran and Timberlake, 95.

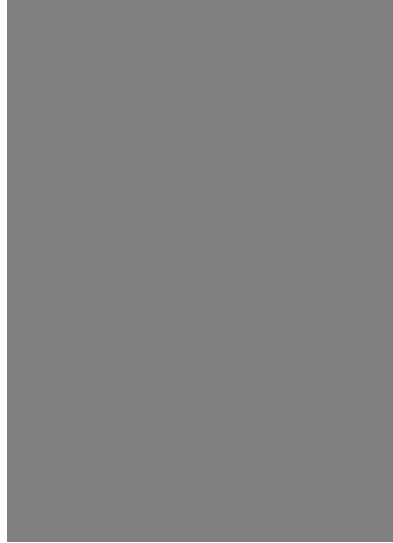


Figure 9 Integrated component assemblies would create less parts needed for assembly (Kieran and Timberlake, 94.).

Chap 2 - Prefabrication Typologies:

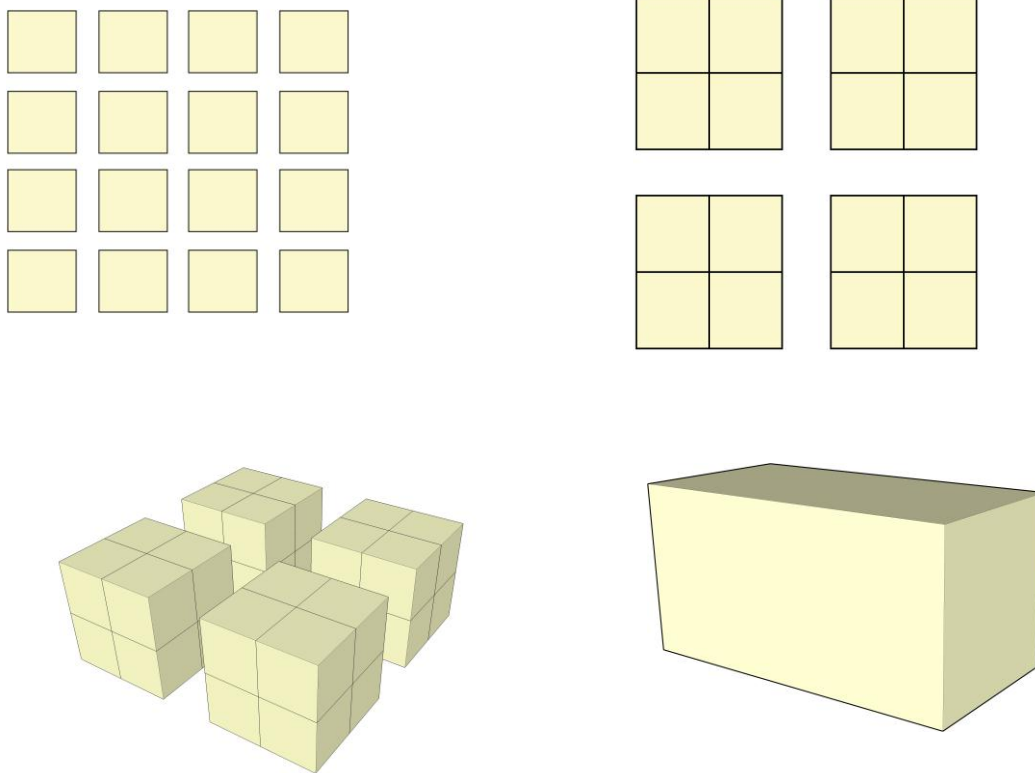


Figure 10 Prefabrication has different typologies with different advantages.

Precut: A precut house modifies individual pieces in a factory to specific dimensions, facilitating an easier construction process while saving time and costs. Construction of a precut house usually requires the aid of a contractor; a common example of a precut fabrication is log houses. The prefabrication method requiring the most on-site construction time is precut manufacturing.¹⁶

¹⁶ Watkins A.M, 51.

Panelized: Panelized houses are similar to precut houses, but integrate individual parts into larger sections before delivering it to the site. This reduces the amount of parts, and therefore saves on-site construction time and costs. The quality of fabrication is another advantage to panelized houses, since the crafting of modules takes place in factories.

Panels are crafted for the walls, the roof, and the floor, and usually come in modules of four foot wide, reflecting the dimensions of plywood. However, panels are also fabricated at six and eight foot dimension¹⁷. Panels are made at the dimensions of an even integer to eliminate waste. For example, if a six foot panel was modified on site to fit a four foot dimension slot, than the other two feet of panel could potentially be used for a corner condition. The maximum width of a panel is typically twenty four feet. Panels can either be fabricated as open or closed. A closed panel is usually more efficient because the wiring and insulation is added in the factory. An open panel is chosen if the client decides to use different insulation materials than what the factory is producing and is delivered simply as the frame, needing additional work on site. Panelized systems allow for either a contractor or an experienced client to construct the home.¹⁸

Modular: Modular houses are constructed in factories ensuring the highest possible quality of fabrication. The controlled environment allows for better working conditions, easy access to tools, less waste, and shelter.

¹⁷ Anderson Anderson, 148.

¹⁸ Watkins, A.M., 48.

Other advantages of modular fabrication are that it reduces the number of parts needed for on-site assembly, which saves time and costs. Modular housing is also built stronger to withstand the traveling conditions to the site. Disadvantages are that larger modules are more expensive to deliver, and that it requires larger cranes on site. Also, sometimes on-site construction provides job opportunities for local workers¹⁹.

The size of the modules is limited by the dimensions of the truck. Without a permit, the dimensions are limited to 40 ft long, 8.5 ft wide and 13.5 ft high. If a permit is attained, then the size of the modules can increase to 55ft long, 16ft wide, and 13.5ft high, but this impacts the price, driving costs higher (Fig. 11).²⁰



Figure 11 Truck Dimensions. Image taken from Bigstock.com. Accessed 12.14.10

Manufactured Housing (Mobile Houses): Mobile houses, which are now called

¹⁹ Watkins, A. M., 35.

²⁰ District of Columbia Municipal Regulations. Size, Weight, Construction, and Loading of Vehicles. edited by Municipal Regulations. (District of Columbia: Final Rulemaking, March 20, 1997.)

http://os.dc.gov/os/lib/os/info/odai/title_18/chapter_25.pdf (12 December 2010). 25-1 – 25-11.

manufactured houses, are constructed in a factory on a chassis and delivered to the site completely finished. For this reason, the price of a manufactured house is much lower than a conventionally constructed house. As of 1976, manufactured houses were required to meet building codes that were developed by the U.S. Department of Housing and Urban Development (HUD). Mobile houses, however, need to be assessed differently than conventional houses since their value and financing are dissimilar.²¹

Kit of Parts (Precut or Panelized):

The concept of a house fabricated from a kit of parts integrates the ideas of prefabrication and customization; it increases efficiency and costs, but creates opportunity for owners to modify the design based on their own preferences (Fig. 12). The construction method for a kit house includes either precut or panelized prefabrication. Owners usually have an array of choices for plan layouts and materials.²²

²¹ Watkins, 73

²² Joanna Wissinger, and Philip Lief Group. *The Best Kit Homes : Save Time and Money on Your Customized Dream House*. (Emmaus, Pa.: Rodale Press, 1987), 10.



Figure 12 Panelized construction saves on-site construction time (Kieran and Timberlake, 40).

Prefabrication began in the 1890's with companies such as Hodgson Homes, Alladin Homes, and Montgomery Ward. Sears, Roebuck and Co. was a pioneer of mass production, selling over 100,000 affordable quality houses that were purchased through catalogues (Fig. 13). The catalogues offered many design options for the house which would eventually be mail-ordered to the site. The houses came in twenty two different styles that cost between \$650 and \$2500 in the early twentieth century, and would be delivered in 30,000 pieces.²³ This methodology of constructing houses is still currently used by companies like Ikea, in collaboration with Skanska as evidenced by their design for low-end prefab houses.

²³ Wissinger, 7.



Figure 13 Sears, Roebuck and Co. sold over 100,000 quality but cheap houses (Sears, Roebuck and Company Mail Order House Survey) 80.

The need for cheap and available housing during WWII initiated the design for the Nissen and the Quonset Hut. Quonset Hut's were prefabricated with a metal ribbed structure, and were both cheap and portable, making it ideal for shelters during the war (Fig. 14). The 170,000 units used during WWII were assembled very easily.²⁴

²⁴ Allison Arieff and Bryan Burkhart. *Prefab*. (Layton: Gibbs Smith, 2002), 21.



Figure 14 (Arieff and Burkhart, 21)

Joseph Eichler was a manufacturer who designed award winning architectural houses that were well crafted modern dwellings. He was inspired by the architectural richness of the Frank Lloyd Wright houses, but instead wanted to recreate the quality of the dwellings for middle class families. Eichler used a lot of prefabricated parts that enabled him to build cheaper houses, however he did not sacrifice materials just for easier and cheaper construction like many of his contemporaries.²⁵

²⁵ Jerry Ditto, Marvin Wax, and Lanning Stern. *Eichler Homes : Design for Living*. San Francisco: Chronicle Books, 1995.

Modular Housing:

Modular housing includes any type of house manufactured through a production-line operation in a significant phase of production (Reidelbach). Usually, modular housing is about ninety-five percent finished in the factory.

The first recorded modular, mobile house was the Conestoga wagon in the 1700s (Fig. 15). These vehicles acted as both a form of dwelling and transportation, but their usage declined with the development of the railway system.²⁶



Figure 15 The Conestoga wagon was the earliest forms of a mobile house (Rudolph, 3.2).

The concept of modular housing was attractive to many modern architects such as Walter Gropius, Mies van der Rohe, and Le Corbusier. Le Corbusier believed in the idea of a “machine for living,” predicting that the future of housing would entail production processes similar to machines such as airplanes and cars. Theoretically, the houses would be erected in a few days compared to the long construction processes of

²⁶ Paul Rudolph, and University of Maryland College Park. School of Architecture. *Modular Housing Study*. (College Park, Md.: University of Maryland, College Park, School of Architecture, 1977). 3.2

conventional housing methods. Lighter materials would be used with stronger structural properties as a replacement for the traditionally heavy materials. Le Corbusier's concept represented a transformation in philosophy; houses would function similar to tools, abandoning their notion as an expensive permanent dwelling. These ideas are illustrated in the way Le Corbusier conceived the Citrohan House and the Domino House (Fig. 16).²⁷



Figure 16 Le Corbusier's idea for the Citrohan House was based on mass production (EtcHELLS, 223).

Similar to Le Corbusier's idea of a machine for living, Walter Gropius stated that "we want an architecture adapted to our world of machines," expressing his idea of transforming the method by which buildings were fabricated. Gropius was interested in the industrialization process of creating mass housing and prefabrication in order to improve the labor time which "enslaved" workers.

His Toerten houses in 1927 were built through assembly-line construction for low-income families. This process was capable of a one hundred and thirty house output

²⁷ Le Corbusier. *Towards a New Architecture*. (New York,: Praeger, 1970). 211.

in eighty-eight days. He continued to develop his prefabricated methodology for affordable housing with the experimental housing for the Werkbund Exhibit Committee in Stuttgart Germany, and with the design of his Copper Houses, in 1931. The Packaged House System (1942-52) designed for General Panel Corporations was created with modules that were interchangeable and allowed for flexibility with an interlocking metal joint. Wood panels were fabricated to be assembled both horizontally and vertically depending on whether the panels were for the walls, ceiling, or floors.

Buckminster Fuller was not an architect, but he challenged the notion of building as a philosopher while promoting mass production and industrialization. A manifesto he wrote called “4D” responded to the problem regarding mass production stated in “Towards a New Architecture” by Le Corbusier.²⁸ Fuller described traditional house construction as primitive. He advocated that houses should imitate the construction methodology used by cars. Air transportation was Fuller’s solution to the restricted dimensions of truck delivery (Fig. 17).²⁹

²⁸ Michael John Gorman. *Buckminster Fuller : Designing for Mobility*. (Italy:Milan 2005), 23.

²⁹ Gorman, 36.



Figure 17 Buckminster Fuller imagined air travel as the delivery method of the future (Gorman, 38).

Fuller's vision of delivering modular housing by airplanes was conceived in his scheme for the Lightful Towers. His Dymaxion House, 1929, was a prototype illustrating the ideals of construction efficiency and functionalism through advanced technology. The Dymaxion Dwelling Machine was designed for the Beech Aircraft plant in Wichita, Kansas. Using advanced aircraft technology, it was able to protect against the recurrent tornadoes in Kansas. Although the Dymaxion Dwelling Machine had the potential for mass production, only one was ever built (Fig. 18).³⁰

³⁰ Gorman, 41.



Figure 18 The Dymaxion House was designed as a industrial produced house (Gorman, 42).

Jean Prouve was an innovator for prefabrication and industrialization methods. Trained as an ironworker, he combined the idea of industrialization with art, and worked with metal and plastics to invent new forms. He developed the BLPS vacation home using prefabricated steel and designed it with the ability to be assembled or disassembled by five men in only four to five hours. Jean Prouve's ultimate goal of creating the maneuverability of houses was illustrated in the way the Tropical House of Brazzaville was assembled and disassembled from France to Africa. This was achieved through effective prefabrication methods that minimized the number of parts, and dimensioned them to fit the cutting and pressing machines. The manufactured parts were limited to one hundred kilos, enabling the Tropical House to be easily handled by only two men. After much deterioration, the house was moved back to France and has since been used as a tool to communicate the potential of prefabrication. Exhibitions have focused on displaying the building systems instead of the completed structure, with the intentions of

demonstrating technology and industrialization as a solution for construction.³¹

Modular prefabrication was a useful tool in creating available shelters during World War II. The need for refuges, kitchens, and aid stations made trailers especially important since they could be delivered quickly by truck. The form of trailers, however, was often criticized as unappealing. The trailer form was relieved with the creation of the Tennessee Valley Authority's Sectional House, which was delivered to construction sites via two halves.³²

Following WWII, the lack of housing made modular fabrication an important asset to marketing houses that were readily available at an affordable price. Abraham Levitt responded with the creation of Levittown, featuring modular houses that were built by means of an assembly line. This method could produce thirty houses per day, and would continue at this frenetic pace until 6000 were manufactured.³³

³¹ Peter Sulzer and Erika Sulzer-Kleinemeier. *Jean Prouvé, Highlights : 1917-1944*. (Basel ; Boston: Birkhäuser, 2002.)

³² Rudolph, 3.3.

³³ Arieff and Burkhart, 27.

Chapter 3 - Construction Methodologies:

Panelized 2x4/ 2x6 Systems:

Project: Fox Island House

Architect: Anderson Anderson Architecture

Location: Gig Harbor, Washington

Year: 1992

The panelized framing system is a simple prefabrication method that is even used with most site-built construction. Prefabrication allows wall panels to be assembled in the horizontal plane, thereby facilitating ease of assembly. The completed panel is then rotated ninety degrees to become a building component. These panels are constructed offsite in a controlled environment, making the construction process more consistent and efficient. The panels require additional structure to withstand the transportation process. The size of the panels delivered to the site is often dictated by the size limitations of the truck. Larger panels reduce the construction time and costs, however are limited to the 8.5ft truck dimensions. Permits can be acquired to allow for larger loads; however, transportation costs go up. Also, larger panels can be placed vertically or diagonally in the container with the cost of reduced load efficiency.³⁴

³⁴ Anderson Anderson, 24.



Figure 19 Prefabricated panels created a quick construction process (Anderson Anderson, 28).

The Fox Island House utilizes a 2x6 framing panelized prefabrication system for both construction efficiency and for aesthetics (Fig. 19). The panels were fabricated offsite at eight feet wide, and were customized on site and manipulated to fit along the topography. The framing continued through most of the wall openings to optimize the strength of the structure, to celebrate the structure, and to remove the need for trimmers and headers. Once on site, the frame was constructed in only six hours because of the efficiency and rationality of the prefabricated panels.³⁵

³⁵ Anderson Anderson, 26.

CNC Timber Framing (4x4 and larger):

Project: Marrowstone Island House

Architect: Anderson Anderson Architecture

Location: Marrowstone Island, Washington

Year: 2003

A Computer Numeric Control (CNC) timber-milling machine is a prefabrication tool which reduces the amount of labor needed for timber framing construction.

Conventional timber framing is not very efficient. Timber framing is a traditional construction method that is used because of its elaborate joinery methods. However, the amount of labor required for its construction decreased the use of timber, until the CNC machines were invented. Timber framing elements can be strengthened with steel connectors, transforming the joined pieces into a rigid connection. An advantage to timber framing is that it can easily incorporate other prefabricated systems, such as panelized framing system and structural insulated panels (SIP).³⁶

³⁶ Anderson Anderson, 45.



Figure 20 Shop drawing served as instructions for for manufacturing the timber frame (Anderson Anderson, 56).

The Marrowstone Island House took advantage of CAD/CAM milling machines to efficiently fabricate the house offsite. A CAD/CAM software interprets 3D images into codes to program the milling machine. Prefabricating the parts with a milling machine was particularly important due to the difficulty of accessing the house's island location; the construction process would not have been feasible with on-site construction. Shop drawings were made as instructions to the fabrication of the timber elements with the CNC machine (Fig. 20).

Another form of prefabrication was used for the enclosure of the building. The house program was separated into modular components that were placed under the timber framing of the house in order to expose and celebrate the timber. The first modular component consisted of a kitchen and a family room, while the other modular box

contained the bedrooms, bathrooms, and laundry room. This prefabrication method of timber framing used a steel connector assembly to produce a modern timber structure.³⁷

Concrete Systems:

Project: Concrete Tower House 1 and 2

Architect: Anderson Anderson Architecture

Location: San Francisco, California and Seattle, Washington

Year: 2005

The use of concrete is advantageous for many reasons, including low cost, flexibility of form, fire resistance, thermal mass characteristics, sound insulating elements, and low maintenance. Concrete becomes even more desirable with prefabrication methods that reduce labor and costs. Concrete Masonry Units (CMU) come at standard dimensions of 8 x 8 x 16 in. and can be assembled in different ways to produce different shapes. CMU construction is now used more than brick, since it is easier to build with and because it has better structural properties. Autoclaved Aerated Concrete (AAC) is an improved version of CMU. It has better insulation properties, but does not weigh as much, making it easier to handle. Also, its reduced weight allows for creation of larger components offsite. AAC is created by adding aluminum powder to the concrete mix which makes it expand when it cures. Prefabricated concrete can also be associated with the form work used to shape the onsite poured concrete, and with pre-cast concrete.³⁸

³⁷ Anderson Anderson, 50.

³⁸ Anderson Anderson, 83.

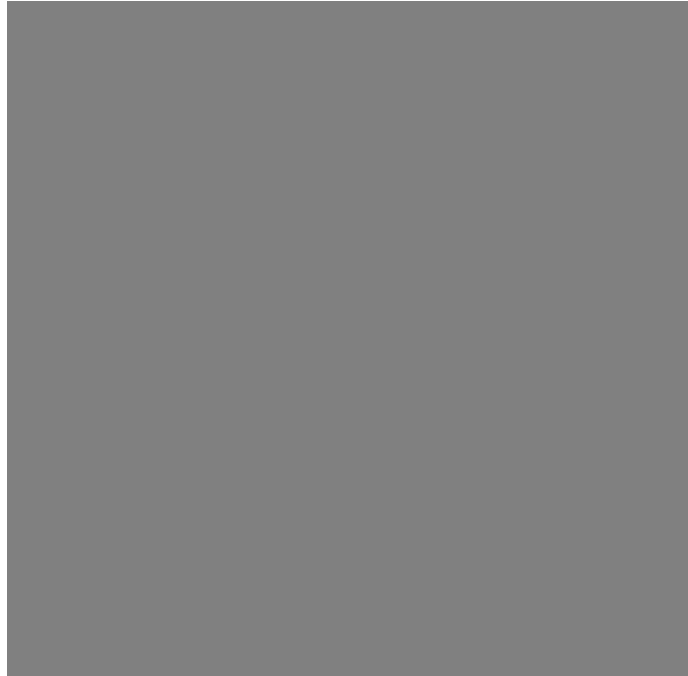


Figure 21 Composite Panels reduce on-site construction time (Anderson Anderson, 89).

The Concrete Tower Houses 1 and 2 are being built on sites with extreme slopes, making construction there extremely difficult and dangerous. The locations in San Francisco and Seattle are also dense, making it desirable to reduce the amount of onsite construction time. To solve this problem, Anderson Anderson Architecture is using prefabricated methods of advanced technological composite panels (Fig. 21). Invented by IHI Corporation in Vancouver, these panels are comprised of rectangular hollow steel tube frames filled with polystyrene foam insulation and covered with fiber-reinforced concrete. These panels are important because they have good insulation properties and can also be used as finished surfaces, eliminating the need for other materials.

Additionally, Anderson Anderson Architecture is collaborating with IHI to produce well insulated and structured foundation walls that can be added immediately after excavation. Anderson Anderson Architects are using concrete and prefabricated methods to create

safe construction on difficult sites while also reducing the construction time.³⁹

Steel Framing:

Project: Cantilever House

Architect: Anderson Anderson Architecture

Location: Granite Falls, Washington

Year: 2004

Characteristics of steel include a high strength-to-weight ratio which gives it advantages for constructing long spans, cantilevers, taller buildings, and more openness. Traditionally, steel has been too expensive to apply to the smaller residential scale, but recently the attitude has shifted because of the consistent quality it produces and because steel manufacturers have started producing steel to the scale of houses. Steel and Wood framing follow similar modules, allowing for the interchangeability of parts.⁴⁰

³⁹ Anderson Anderson, 86.

⁴⁰ Anderson Anderson, 111.



Figure 22 The Cantilever House is built with prefabricated steel modules (Anderson Anderson, 121).

The Cantilever house uses steel to build the house on a difficult site. The steel allows for the house to cantilever out over a small foundation footprint (Fig. 22). Multiple prefabrication systems are used for the house, taking advantage of the different attributes associated with each system; this in effect reduces the cost and improves the quality of the house. Besides the prefabricated steel framing, the house incorporates structural insulated panels (SIPs) for all the surfaces. These prefabrication methods permit construction of the foundation and enclosure to be fabricated in only four weeks,

with an additional six weeks to install the mechanical system and apply the finishes.⁴¹

⁴¹ Anderson Anderson, 117.

Sandwich Panels:

Project: Chameleon House

Architect: Anderson Anderson Architecture

Location: Northport, Michigan

Year: 2002

Sandwich panels are an advanced paneling system that combines materials with both insulator and structural properties. Frank Lloyd Wright experimented with sandwich panels in his Usonian houses in the 1930's, however they lacked structural and insulation properties. As the panels evolved, they also included finishes on the interior and exterior surfaces to decrease on-site labor. Sandwich panels today are called structurally insulated panels (SIPs) and usually contain a layer of insulation (EPS) between plywood or oriented strand board (OSB). Although structurally OSB is stronger with fewer flaws to the material, plywood is better at protecting against moisture. Advantages of a SIP panel include the inclusion of sustainable materials and low costs. The size of SIPs is generally four feet wide with a maximum of twenty-four feet, reflecting the typical proportions of plywood. SIPs are convenient because they can be used for all surfaces.⁴²

⁴² Anderson Anderson, 147.



Figure 23 The Chameleon House uses SIPs to reduce on-site construction (Anderson Anderson, 157).

The Chameleon House was designed to capture the views of Lake Michigan, as it rises through the sloping topography in nine different levels. In order to keep the cost of the house down, SIPs were used as the roof and wall materials (Fig. 23). Additionally, the insulation in the SIPs was advantageous in the cold climate of Michigan. The cost of the house ended up being half of the site-built cost.⁴³

⁴³ Anderson Anderson, 150.

Chapter 4 - Case Studies:

Project: Glidehouse, Sunset Breezehouse

Architect: Michelle Kaufmann

Location: Hot, humid climates (intended for western climates)

Michelle Kaufmann is an architect currently designing modular houses, combining both prefabricated techniques with sustainability strategies. Her goal is to create affordable houses that sit lightly on the earth. Inspired by the fact that buildings are the largest energy consumers on earth and that they use more emissions than transportation in our country, Kaufmann created five EcoPrinciples that dictate her designs: smart design, eco-materials, energy efficiency, water conservation, and healthy environment.⁴⁴

The ability for an architectural office to adapt to change based on current economic situations is important to the longevity of the firm; Kaufmann's office has evolved to sustain more security. While working at mkDesigns, Kaufmann's branch of the firm owned their own factories, enabling them to construct their designs. However, during the economic recession, two of the factories owned by mkDesigns went bankrupt, forcing her to terminate their office. Kaufmann then started her own firm and implemented the strategy of outsourcing to third party factories, reducing the cost of owning a factory and decreased the risk of bankruptcy.⁴⁵

⁴⁴ Kaufmann and Remick, 44.

⁴⁵ Zach Mortice. "Michelle Kaufmann Scales Down to Scale up Pre-Fab." (The American Institute of Architects) 2010. <<http://www.aia.org/practicing/AIAB085948>> (13 December 2010).

Michelle Kaufmann's projects prove the effectiveness of prefabricated housing and importance sustainability and customization. The Glidehouse designed by Kaufmann exemplifies flexibility and sustainability. Kaufmann presents many options for the house so that every client can customize their own house in accordance to their preferences (Fig. 24). The Glidehouse comprises many options such as the number of rooms, whether the house is one or two stories, and various materials and finishes. Connection to the outdoors, which is an important principle in Kaufmann's design, is achieved through sliding doors that open to the courtyard.⁴⁶



Figure 24 Typical layout of the Glidehouse (<http://www.mkdesigns.com>). Accessed 12.14.10

⁴⁶ Kaufmann and Remick, 74.



Figure 25 The Glidehouse has customization of modules (<http://www.mkdesigns.com>). Accessed 12.14.10

Michelle Kaufmann tested the initial Glidehouse as her personal house; it took only twenty one months to construct. In comparison, the Reid Glidehouse was built as modules in a factory and only took ten months to construct, demonstrating the efficiency of prefabrication. Programmatically the typical Glidehouse is comprised of three base modules. One module consists of bedrooms, bathrooms and an office at forty eight feet by seventeen feet (fig 24). The second module includes the living room, dining room and kitchen, also at forty eight feet by seventeen feet, and the last module is just open space at seventeen feet by sixteen feet. The Glidehouse presents many optional modules to add to the base configuration, which include an office and different bedroom modules.⁴⁷

⁴⁷ "Mkdesigns." Blu Homes, Inc., http://www.mkdesigns.com/wp-content/uploads/2010/08/mkD-Glidehouse_08_10.pdf.



Figure 26 Installation of weeHouse (tinyhouseblog.com) Accessed 12.14.10

Project: weeHouse

Architect: Alchemy Architects

Location: Can be delivered anywhere in the United States and most of Canada

Similar to Michelle Kaufmann, Alchemy Architects make sustainability an important element to their design. The weeHouse is a series of houses that have been fabricated to meet the standards of EnergyStar, Build it Green, and LEED. Affordability and flexibility of materials and programmatic functions were two of the inspired goals for the design by Alchemy Architects.⁴⁸ They are designed at various sizes and range in cost from between \$79,000 to \$245,000. A weeHouse is delivered completely finished with appliances; the modules are easily transported with a width of only fourteen feet. The

⁴⁸ Martin Nicholas Kunz, and Michelle Galindo. *Best Designed Modular Houses*. Stuttgart: AVedition, 2005.

———. *Best Designed Modular Houses*. (Stuttgart: AVedition, 2005), 20.

modules of a weeHouse can be attached or stacked to create different configurations for the client (Fig. 29).⁴⁹

Project: Cellophane House, Loblolly House

Architect: Kieran Timberlake

Location: Exhibited at MoMa, Chesapeake Bay



Figure 27 The rooms of the Cellophane House are modular and can aggregate in various ways to fit the context (Home Delivery Fabricating the Modern Dwelling). Accessed 12.14.10.

Kieran Timberlake is a firm pioneering the prefabrication of houses. Their goal is to combine the elements of modularization, customization and sustainability.

⁴⁹ "Prefabs." Site Method Media, LLC.,

<<http://www.prefabs.com/PrefabHomes/AlchemyArchitects/weeStudio.htm>> (13 December 2010).

Kieran Timberlake's Cellophane House, displayed at the Museum of Modern Art's (MoMA) Home Delivery: *Fabricating the Modern Dwelling* exhibit is unique since it is designed with no intent for permanence. It is manufactured of structural aluminum, and simple bolt connections enabling ease of assembly and disassembly. The use of prefabricated components enabled the house to be constructed in less than one week. Sustainability is also an asset of the Cellophane House. The materials are recyclable, and the house generates most of its own energy and uses passive solar techniques for both heating and cooling.

Flexibility is an important characteristic of the Cellophane House. The rooms of the house are modular, and can aggregate differently to fit within the context (Fig. 27). The floor plans are all customizable to adapt to the dweller's needs.⁵⁰

In regards to technology, Kieran Timberlake used Building Information Modeling (BIM) to efficiently design the Cellophane House. The use of BIM enabled Kieran Timberlake to quickly visualize the design of the modular components and transition easily from the design phase to construction.⁵¹

⁵⁰ "Cellophane House." Home Delivery Fabricating the Modern Dwelling. MoMA.

<<http://www.momahomedelivery.org>> 13 December 2010.

⁵¹ Mortice, Zach. "Michelle Kaufmann Scales Down to Scale up Pre-Fab." The American Institute of Architects, 2008. <http://info.aia.org/aiarchitect/thisweek08/0905/0905n_prefab.cfm> 13 December 2010



Figure 28 Computer Image of Loblolly House. (www.aecbytes.com). Accessed 12.14.10

Another house designed by Kieran Timberlake, the Loblolly House located at the Chesapeake Bay, uses advanced prefabricated techniques to ensure precision and a speedy construction process. Kieran Timberlake established a framework on site that acts as scaffolding for the integrated assemblies constructed offsite. All the integrated assemblies and pieces of the house are modeled in the computer beforehand to allow for visualization of connections (Fig. 28). These programmed parts are then sent to computerized cutters, and the modules are assembled in a factory and are built to include mechanical and plumbing systems. The reason for using these prefabricated methods is that it creates uniformity and unity with a fast construction time. Kieran Timberlake's vision for architecture is to transform the way things are built, with the use of better technology.⁵²

⁵² Cilento, Karen. "Loblolly House / Kieran Timberlake." <<http://www.archdaily.com/64043/loblolly-house-kieran-timberlake/>> 13 December 2010

Project: Instant House

Architect: Larry Sass

Location: Exhibited at MoMa



Figure 29 The Instant House uses notches as a simple method of assembly (Home Delivery Fabricating the Modern Dwelling). Accessed 12.14.10.

Instant House is a concept derived by Larry Sass, Associate professor at the Massachusetts Institute of Technology; he utilizes technology to construct shelters economically and with speed. Taking advantage of technology, his students used laser cutters and 3D modeling to construct a prototype of the Instant House, creating notches as the method of joining parts (Fig. 29). This concept proved efficient, as the students fabricated a full scale house made of plywood in three days while only using rubber mallets. Sass continued to evolve these concepts and applied them as a solution for the need for fast and cheap housing in New Orleans. His methodology for solving the problems was through the means of digital technology and automated generators, which demonstrated the potential of technology as a tool. This process is significant as it takes

advantage of technology to create fast and cheap housing. The Instant House if mass produced could potentially be sold for around \$40,000.⁵³

Using advanced technology as the methodology for the fabrication of parts, it created a low technology solution for constructing the house. The concept of using technology as a tool for a design-build project is a feasible idea for this thesis, since there is accessible technology and it would create the option for prototypes to be tested.

Project: System3

Architect: Oskar Leo Kaufmann and Albert Ruf

Location: Exhibited at MoMa



Figure 30 System 3's flexibility allows for potential growth by the stackign of units (System 3). Accessed 12.14.10.

System3 is a house designed by Oskar Leo Kaufmann and Albert Ruf, comprised of modules that allow for flexibility of expansion (Fig. 30). The module is separated into two spaces of “serving space” and “naked space” (System3). The serving space contains

⁵³ “Digitally Fabricating Housing for New Orleans.” Home Delivery Fabricating the Modern Dwelling. MoMA. <<http://www.momahomedelivery.org> > 13 December 2010.

all the support systems and vertical circulation, allowing for the stacking of units. This is significant, as it permits up to thirty stacked units, or even a ten story office tower. The dimensions of the module are designed to be delivered in a shipping container. At \$130,000, System3 is cheaper than the average traditionally constructed house.⁵⁴

Project: Burst*008

Architect: Jeremy Eminston and Douglass Gauthier

Location: Exhibited at MoMa



Figure 31 Digital modeling is used to quickly visualize customized designs (BURST*08). Accessed 12.14.10

Burst*008 also use advanced technological methods as a means to create prefabricated houses at a fast rate. Designers Jeremy Edminston and Douglass Gauthier created a code using “analogue parametric” that has the ability to manipulate designs based on the client’s preferences in as little as a few seconds (Fig. 31). After the architect and the client customize the house on the computer, the Form Z model explodes it into

⁵⁴ “System3.” Home Delivery Fabricating the Modern Dwelling. MoMA. <<http://www.momahomedelivery.org> > 13 December 2010.

1,100 pieces, which are then delivered separately to the site. This method proves to be extremely efficient, saving time and money in both construction and design phase. The total cost of the project was \$250,000.⁵⁵

Project: Dunescape and Virgin Atlantic Clubhouse

Architect: Greg Pasquerelli

Location: Long Island, NY, and JFK International Airport

Greg Pasquerelli, principal of SHOP Architects, has challenged the philosophy of how to run a firm and the methodology of how to design. Based on creating performance based affordable buildings, his firm has been re-inventing the conventional construction process. The firm is comprised of five principals, all from different backgrounds, who dictate the attitude that there are many methods to solving problems without one defined style.⁵⁶

SHOP Architects challenges the philosophy of a running a typical architecture firm by trying to incorporate business and academics into their culture. While the typical firm is comprised of “paper based” and not “service based” architects, SHOP Architects strive to have both(Fig. 32). A paper based architect is more academically oriented, while a service based architect focuses more on business. By combining these two, it allows for the firm to create their own designs and shop drawings. The advantage of

⁵⁵ “BURST*08.” Home Delivery Fabricating the Modern Dwelling. MoMA.
<<http://www.momahomedelivery.org>> 13 December 2010.

⁵⁶ Pasquarelli, Gregg. *Out of Practice*. 2007 Colden “Coke” Florance Lecture. University of Maryland, College Park, 2007.

making their own shop drawings is that it eliminates a loss of translation between the architect and the contractors. Contractors are usually contacted on day one of a project for advice on construction techniques.⁵⁷

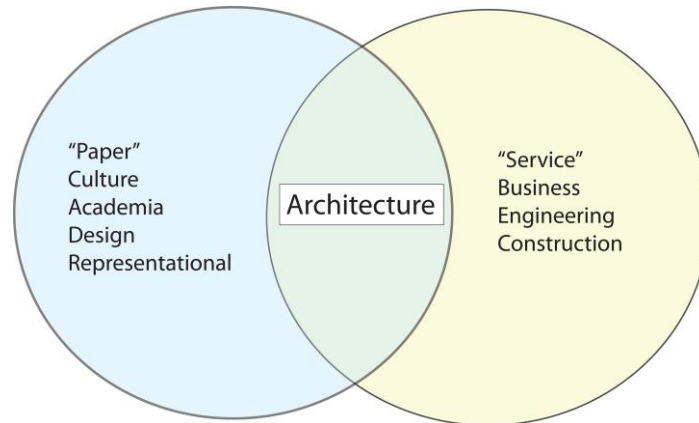


Figure 32 Comparison between a "paper" based architect and a "service" based architect.

During the evolution of SHOP Architects, the principals established a design methodology based on prefabrication and performance based design. SHOP Architects looked at aerospace and automotive industries, since these industries are the epitome of performance based design. The philosophy behind the concept of performance based is that the beauty of the design is in the performance, and that a building functioning properly makes a good design. Technology and computers are the main tools used for designing a performance based design, since they help communicate the ideas of the architect to the manufacturers.⁵⁸

⁵⁷ Pasquarelli

⁵⁸ Pasquarelli



Figure 33 SHoP Architects create a performance based design by combing the structure, skin and program into one thickness"Dunescape at P.S.1 Moma." (<http://www.shoparc.com>). Accessed 12.14.10

SHOP Architects' design for the Young Architects Program, a competition sponsored by The Museum of Modern Art and P.S.I Contemporary Art Center, illustrates their ideal of a performance based design; the structure, skin, and program are all combined into one thickness. One surface made up of sticks created an urban beach responding to all the programmatic elements, acting as a shading device, a place for sitting, dancing, sitting, and getting wet (Fig. 33).⁵⁹

⁵⁹ Pasquarelli



Figure 34 Components of Virgin Atlantic Clubhouse (<http://www.shoparc.com>). Accessed 12.14.10

SHoP Architects' design for a first class lounge for Virgin Atlantic took advantage of prefabrication when conventional manufacturing was not possible. Restrictions regarding security made construction difficult, since this project was created soon after 9/11 and they were not allowed to use anything larger than furniture. SHOP Architects was able to prefabricate all the elements of the design into a kit, based on the officials' definition that furniture was anything that could fit into a 4x4x4 foot box (Fig. 34).⁶⁰

⁶⁰ Pasquarelli

Project: LV Series

Architect: Rocio Romero

Location: Projects available in United States



Figure 35 Image of flatpacked components. (www.rociromero.com). Accessed 12.14.10.

Rocio Romero is a contemporary architect who uses mass customization to create personalized houses at an affordable price. He created the LV series of houses that are flatpacked as a kit of parts (Fig.35). Advantages to the LV series include an affordable price and customization. It can qualify for a traditional mortgage unlike modular houses.⁶¹

Project: The Villa

Architect: Daniel Libeskind

Location: Available worldwide

Daniel Libeskind: A critique of modular mass produced housing is that it creates repetitious buildings resulting in banal architecture. While Le Corbusier would argue that repeated forms are beautiful and promotes organization, many people fear a

⁶¹ Arieff and Burkhart, 57.

repetitive trailer-like environment. Daniel Libeskind's approach attempts to create the efficiency of mass production without triteness by limiting only one villa per community. The Villa is a house which is mass produced as kit-of-parts that can be constructed in a few weeks on site. (Fig. 36).⁶²



Figure 36 Daniel Libeskind limits production of the villa to avoid repetitiveness

(Libeskind Designs a Prefab Home). Accessed 12.14.10.

Summary: The common denominator of all the case studies is that the houses involve prefabrication. However, each example is defined differently by varying philosophies, methodologies, and typologies. To conclude these case studies, these different facets of the prefabricated houses will be examined further.

Philosophy:

Sustainability: Michelle Kaufmann, Alchemy Architects, and Kieran Timberlake all had sustainability as a major design proponent. Kaufmann's five EcoPrinciples guide her

⁶² Kevin Brass. "Libeskind Designs a Prefab Home." The New York Times, <<http://www.nytimes.com/2009/06/12/greathomesanddestinations/12iht-relib.html>> 13 December 2010

designs. In the Glidehouse, sustainability impacts the form by creating a breeze space for ventilation. Alchemy Architects' weeHouse is LEED certified, and the Cellophane house uses recyclable materials, and also generates most of its own energy.

Office/Business: The philosophies guiding Michelle Kaufmann's firm and SHOP Architects position them to gain an advantage in business and design. Michelle Kaufmann changed the way her firm handled business with the fabrication factories to prevent future risks of bankruptcy for her firm. Greg Pasquerelli and SHOP Architects implemented an office philosophy that would improve efficiency and quality. By involving contractors early on and creating their own shop drawings, SHOP Architects eliminate the risk of having their design misinterpreted by contractors.

Flexibility: The Cellophane House by Kieran Timberlake and the System 3 house by Oskar Kaufmann and Albert Ruff use the concept of flexibility to allow the design to adapt to the context. Both firms create a system of modules that can be aggregated differently by adjoining or stacking for expansion and flexibility.

Methodology:

Technology: Larry Sass's Instant House and Burst*008 both use technology as a significant tool in the design process. They both created computer programs that could modify their designs at a fast rate, and translate this information into a means of physical fabrication. The use of this method increased efficiency through the means of technology.

Delivery: SHOP Architects used a special delivery method involving prefabricated parts.

The prefabricated parts could be delivered in a 4ft x 4ft x 4ft enabling them to overcome the restrictions placed by the airport.

Typology:

Panelized: Rocio Romero, the Instant House, and Burst*008 all fabricate parts that can be flatpacked to the site. Rocio Romero creates a kit-of-parts that allow for clients to customize their house based on their preferences, which also helps to prevent banality of mass production. Daniel Libeskind prevents banality instead by limiting production to only thirty iterations.

Modular: The Glidehouse, the weeHouse, the Cellophane house and System 3 use modular fabrication to generate quality and reduce the time of construction.

Part 2 – Responding to Natural Disasters

Chapter 5 - Natural Disasters:

Natural disasters can come in the form of earthquakes, tropical storms, wild fires, tsunamis, or volcanoes. These forces are lethal and have caused destruction throughout history. While the impact of natural disasters is devastating, and the forces behind them are unpredictable, designing buildings in accordance to codes that respond to specific disasters relevant to a region can minimize the damage. The majority of casualties occur in developing countries that have dense populations on land susceptible for disaster; often with less advanced method of warning.

Hurricane/ Typhoon/ Tropical Cyclone:

Destruction caused by strong winds in the warm ocean regions are known as hurricanes in the areas around the United States, Mexico and Caribbean, typhoons in the North Pacific area and China Sea areas, and tropical cyclones in the Australasian, Indian and African regions. The winds are created from coriolis force, which describes the process of redirecting wind based on the rotation of the earth on its polar axis. Other parameters that dictate the formation of these strong wind storms are water temperature and location. Any type of tropical storm will only form in warm (25 degrees Celsius) ocean waters, between the latitudes of eight degrees and twenty degrees north or south of the equator. When a hurricane transitions to the land, the wind force decrease and transforms into a

tropical storm. Hurricanes can also be associated with flooding in regions that they hit.⁶³

In 2005, Hurricane Katrina caused devastation to the communities along the Gulf Coast of the United States. The flooding from the Hurricane left many people homeless, damaging approximately 300,000 houses. Residential damages totaled seventy-five billion dollars and corrupted the socio-economic balance of New Orleans, Mississippi, and Alabama.⁶⁴

Federal Emergency Management Agency (FEMA) attempted to respond to the housing crisis caused by Hurricane Katrina in New Orleans by creating an assistance program that would provide temporary housing for eighteen months. The goal was “[to help] individuals and communities affected by federally declared disasters return to normal functioning quickly and efficiently.” The problem, however, was that the damages from the hurricane negatively impacted the economy in that region, making it difficult for low and middle-income families to afford the transition from the temporary houses provided by FEMA to a permanent dwelling.⁶⁵

FEMA provided two types of dwellings for the hurricane victims. The

⁶³ John Butler. *Natural Disasters*. (Singapore: K yodo-Shing Loong Printing Industries Pte Ltd, 1979), 43.

⁶⁴ "Two Years after the Storm, Housing Needs in the Gulf Coast." (Hearing before the Committee on Banking, Housing, and Urban Affairs.: US Government Printing Office, 2007), 4.

⁶⁵ "Disaster Housing: Fema Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters." edited by United States Government Accountability Office. Washington D.C., 2009.

manufactured housing (mobile home) was the largest and most expensive type supplied by FEMA. It was larger than eight feet by forty feet, and could have been used as a permanent house. The recreational vehicles provided by FEMA included a park model or a travel trailer. The difference between the park model and the travel trailer was that the park model was larger and could be regulated by construction standards, while state transportation authorities regulated the travel trailer.⁶⁶

The temporary housing provided by FEMA was either placed in proximity to a victim's damaged house for the purpose of overseeing repairs, or on a group site, which contained the majority of the impoverished people who had trouble transitioning to a permanent dwelling. FEMA had originally granted about 25,000 houses for group sites in 2005. Currently there are still 577 people living in the temporary housing units at the group sites.⁶⁷

There were multiple factors that led to the difficulty in transitioning to a permanent dwelling. Along the Gulf Coast region there was an increase in unemployment that peaked at 23.2 percent in the Gulfport-Biloxi metropolitan area of Mississippi. Similarly, the lack of affordable housing and the demand for undamaged dwellings contributed to an increase in housing rent. The focus of federal funds provided a disadvantage for the low-income families in need of rental units since most of the funds went to repairing damaged houses instead of creating new rental units. Only one billion

⁶⁶ Disaster Housing: Fema Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters.

⁶⁷ Disaster Housing: Fema Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters.

out of twenty billion dollars provided by Congress was used for rental units.⁶⁸

The quality of the FEMA houses seemed to suffer as a result of rushing the construction process. Many of the houses have been accused of containing formaldehyde, an industrial chemical that can cause respiratory problems and nasal cancer. The source of the formaldehyde has been suspected to come from plywood imported from China. Since these accusations of causing health problems, FEMA has since banned the use of trailers.⁶⁹

Earthquakes:



Figure 37 Ground Movement (Schodek, 492).

Earthquakes are caused through movement of fault lines, which then release energy in the crust of the earth, sending vibrations along the ground's surface that are called seismic

⁶⁸ Disaster Housing: Fema Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters.

⁶⁹ Disaster Housing: Fema Needs More Detailed Guidance and Performance Measures to Help Ensure Effective Assistance after Major Disasters.

waves. The Primary wave (P wave) travels away from the focus of the earthquake sending vibrations parallel with the wave. The secondary waves (S waves) follows the P wave, with vibrations running perpendicular to the wave. Surface waves (L waves) then follows the S wave and causes most of the damage associated with earthquakes (Natural disasters, butler, 8). The vibrations caused by the earthquake have the potential to cause damage to the buildings, depending on the direction, displacement, acceleration, and duration of the earth's movement. The motion of the ground, whether horizontal, vertical, or through torsion, puts stresses on the building's structure based on the mass of the building and the acceleration of the movement (Fig. 37).⁷⁰

Measuring the Earthquake:

The Richter scale is used to measure the magnitude of the earthquake. The Mercalli scale measures the destruction caused by the earthquake, and is used to map out the different areas of damage around the epicenter of the earthquake.⁷¹

On January 12, 2010, Haiti experienced an earthquake that socially and economically devastated their country. This natural disaster was extremely lethal, killing 1.2 million people and destroying countless homes. In the aftermath of the quake, sanitation problems have caused the spread of disease, and crime has increased due to a lack of security. Also, children are being deprived of their educational needs, with an estimated 985,000 children left without a school to attend. The US Agency for

⁷⁰ Butler, 9.

⁷¹ Butler, 8.

International Development, The International Organization for Migration, UN Humanitarian Affairs, UNICEF and other aid agencies are all organizations that have donated tents, tarps, and portable toilets; however, a disaster so catastrophic will have lingering effects.⁷²

⁷² Leinwand, Donna. "Agencies Race to Help 1.2 Million Homeless in Haiti." *USA Today*, 2010. <http://www.usatoday.com/news/world/2010-02-16-haiti-homeless-tent-city_N.htm> (14 December 2010)

Chapter 6 - Case Study Disaster Relief Housing:

DHI Disaster House:



Figure 38 Picture of DHI Disaster House (Humanizing the Factory Produced House - Rapid Initial Set-up Structures for Long Term Use). Accessed 12.16.10.

Gregg Fleishman studio initially designed the DHI Disaster House to provide housing for the homeless in Los Angeles; it later developed into a means of shelter in areas devastated by natural disasters (Fig. 38).

Based off earlier designs, Fleishman implemented a structure of four foot square plywood panels that were modularized to standardize the assembly method. Moreover, Fleishman increased his efficiency and accuracy of design from his previous projects with the use of digital technology that helped him visualize his design faster and in greater detail.

The DHI Disaster House is fabricated using a CNC router to create a system of notched plywood that is essentially modularizing a set of connections to facilitate an easy

assembly process on site. Handling of the material on site does not require the aid of cranes since the pieces are manufactured into smaller modules. Also, the joinery between any two parts does not require additional hardware. Assembly of the DHI Disaster House at the Anaheim Convention Center only takes three hours and thirty minutes.

In addition to providing an easily constructed dwelling in locations where houses have been destroyed by natural disasters, the DHI Disaster House is a good solution for locations that are prone to earthquakes. The flexibility of the house can respond to the stresses caused by the shaking of an earthquake. Also, The DHI Disaster House only sits on four points at thirty inches above the ground, making it ideal for rough terrain or for flood zones.

The disadvantage of the DHI Disaster House is its cost- \$22,000 - which is probably not economically feasible for many of the victims needing a house.⁷³

⁷³ "Humanizing the Factory Produced House - Rapid Initial Set-up Structures for Long Term Use." Gregg Fleishman, <<http://www.greggfleishman.com/structures.html>> (14 December 2010)

The Pallet House:



Figure 39 Structure of the Pallet House (Leonaora Oppenheim). Accessed 12.16.10.

The Pallet House is designed by I-Beam Design to provide transitional housing for victims who lost their home in a disaster. The Pallet House uses an innovative method of reusing shipping pallets to create the structure of the house, providing means of accessible materials that are easily handled manually on site (Fig. 39). While many designs for disaster relief housing are based off one model that creates banality from repetitiveness, each Pallet House can be massed differently to create individuality amongst other Pallet Houses. Although the Pallet House is meant to provide temporary shelter, vernacular materials can be added to the structure to create permanent structures. Additionally, the pallet structures are inexpensive to build and can be fabricated within a week.⁷⁴

⁷⁴ Leonaora Oppenheim. "Pallet-House: Modular Refugee Housing." Discovery Communications, LLC, <http://www.treehugger.com/files/2006/06/pallet_house.php> (14 December 2010)

The Concrete Canvas House



Figure 40 Views of the Concrete Canvas House (Concrete Canvas). Accessed 12.16.10.

The Concrete Canvas House is designed as temporary housing. Although the domed tent structure does not exude the perception of a comfortable home, it is viable for housing in disaster areas since it has the desired qualities of being inexpensive, easy to assemble, and weather resistant (Fig. 40).

The Concrete Canvas House can be erected in one hour with the labor force of only two people. The process comprises of spreading out the canvas and filling it with water. The structure has to cure for twenty four hours after filled with water.⁷⁵

⁷⁵ "Concrete Canvas." Concrete Canvas Ltd.,
<http://s146224806.websitehome.co.uk/Contact_Information.html> (14 December 2010)

The Floating Container House



Figure 41 Diagram of the Floating Container House (Bridgette Meinhold). Accessed 12.16.10.

The floating Container House provides a solution for dwellings in proximity to flooded areas. It is fabricated as modules from recycled materials such as shipping containers, and is designed to elevate as many as 2.5 meters to adapt to increasing water levels (Fig. 41).⁷⁶

⁷⁶ Bridgette Meinhold. "Floating Container Houses Proposed for Pakistan Flood." <inhabitat, <http://inhabitat.com/floating-container-houses-proposed-for-pakistan-flood/>> (14 December 2010)

Chapter 7 - A System for Recovery:

Natural disasters can cause damage at many levels in regards to the built environment. Depending on the intensity of the disaster, damages can range from houses to large institutional buildings. Following a natural disaster, there is a large focus on providing relief housing. While this is important, the neighborhoods consisting only of houses and no central community center will lack a sense of culture and identity and ultimately struggle to rebuild in the long term. By providing a location that supports needed activities for a given community, neighborhoods can develop around the community center, benefitting the population as a whole and ensuring a sense of social and cultural continuity. Community centers create the notion of ownership and identity, generating pride amongst the individuals of the neighborhood.

Planning and constructing a community center in a country of disarray is challenging. A system of offsite prefabrication would allow for a preplanned building to be delivered in manageable components. This thesis proposes a prefabricated system and a process of construction that will revitalize the community with work opportunities; the end product would provide flexible spaces allowing for adaptability of current needs.

The design of buildings for the cause of disaster relief goes beyond the structure itself. The areas suffering from the damages caused by a natural disaster present many challenges in regards to reconstruction. Without careful consideration of these challenges, the provided relief will fail. The process of the proposed system includes delivery issues, materials as they relate to culture and climate, materials and structure as they relate to

seismic design, handling of manual labor, and local construction skills.

Inspiration for this proposal stems from the horrific events suffered by Haiti and the challenges the disaster caused.

Haiti presents the challenge of designing with both earthquakes and hurricanes in mind. The earthquake of 2010 destroyed many communities, schools, and homes. Additionally, there is a problem of debris and rubble that need to be removed to allow access to reconstruction sites. Haitians have resorted to living in small tents since many of their homes were destroyed. A lack of jobs creates difficulty for Haitians to leave their current state of poverty. The action plan for Haiti states that there are currently 250,000 people living in various camps susceptible to high health and safety risks. The government of Haiti has found the location of five different emergency sites for migrating approximately 100,000 of the people prone to the dangerous areas. These sites will begin as temporary neighborhoods, however; the government views these as neighborhoods that can develop into permanent communities over time. The addition of a community center is supportive of the action plan of Haiti.⁷⁷

The proposed system should include the following elements, facilitating a design that acts as a social and economic catalyst for the community.

⁷⁷ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 32.

Chapter 8 - Action plan for National Recovery and Development of Haiti:

The Impact of the Earthquake:

On January 12th 2010, an earthquake struck Haiti in the cities of Leogane, Jacmel, Petit Goave, and its capital, Port-au-Prince. At a magnitude of 7.3 on the Richter scale, the earthquake had a devastating effect on Haiti's built environment, economy, and social balance. The damage caused by the earthquake was amplified by the dense population and poor building standards. The action plan presented by the government of Haiti is based on the evaluation from Haiti's National officials with the aid of international consultants. They have assessed that costs from damages amount to eight billion dollars.⁷⁸

The earthquake killed 300,000 people and injured another 300,000. 1.3 million people were forced to live in temporary shelters, and another 600,000 migrated to other parts of the country.

The earthquake caused much damage to the residential and social sectors of Haiti's built environment. 105,000 houses were demolished while 208,000 houses were damaged. The earthquake left the metropolis of Port-au-Prince desolate, creating the need for shelters for those left homeless or in poor living conditions.⁷⁹

⁷⁸ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 5.

⁷⁹ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 7.

The loss of over fifty hospitals from the earthquake made it difficult to deal with the spread of diseases caused by the poor living conditions. Also, the 1,500 damaged schools have halted education for children in parts of Haiti.⁸⁰

Haiti's Goals for Recovery:

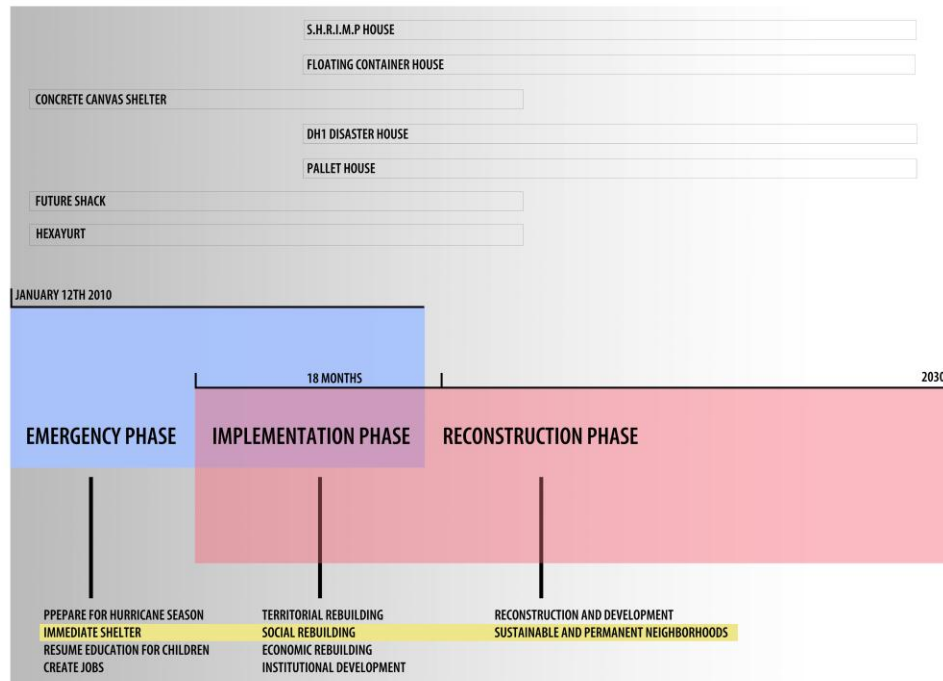


Figure 42 Diagram of recovery goals.

Haiti's goal for redevelopment as stated in the action plan is to restore their country in a better state than it was before the earthquake in 2010 (Fig. 42). The damages from the earthquake have given Haiti an opportunity to improve their country to better withstand earthquakes and hurricanes, and to establish a democratic society. The concentration of redevelopment will focus on territorial rebuilding, economic rebuilding,

⁸⁰ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 7.

social rebuilding, and institutional rebuilding.

Territorial Rebuilding:

Haiti plans to rebuild the country on the scale of the individual properties, of the whole community, and of the whole nation. The first step consists of cleaning up all the debris from the wreckage, and recycling any reusable material. The scattered debris is another challenge to overcome in the recovery process, as it blocks the roads and sites that are used for delivery of supplies.⁸¹

Also, new and improved infrastructure and street networks are essential to the success of the new Haiti. Buildings will have to be carefully manufactured to ensure higher building standards, preventing damages as severe as those after the earthquake.

To prevent other devastating natural disasters, the urban development must be more considerate of where the fault lines are located and to the density of communities. There is a greater level of loss in disaster prone areas that are highly populated.⁸²

Economic Rebuilding:

Redevelopment of Haiti goes beyond the physical reconstruction of buildings. Haiti needs to revitalize its economy to become a stable country. Haiti is an agrarian society, so maximizing production will be essential for the country to become a viable

⁸¹ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 12.

⁸² "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 13.

economy. Since the earthquake, the agricultural production in Haiti has not been enough to sustain the population's need for food. Improving the condition of rural agricultural communities is an important goal stated by the action plan for Haiti.⁸³

With the lack of jobs available in Haiti, it becomes challenging for the population to escape their impoverished state. Disaster relief housing and shelters provide the opportunity to create construction jobs for the local people.⁸⁴

Social Rebuilding:

Establishing healthcare, food security, jobs and education will be important for Haiti to become an emerging country. Without social services, Haiti will continue to be an impoverished nation with major health problems and violence that will be difficult to overcome. The action plan encourages that the culture be a primary element when establishing different social services. Preserving Haitian heritage is important to establish a market valued by their cultural elements and developing communities centered on cultural sites. Establishing a cultural identity will create a sense of pride among the population and relieve them of their dependency on international aid. The action plan administered by Haitian officials demands the implementation of culture into the school curriculum, instituting culture as a core element of the children's education.⁸⁵

⁸³ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 22.

⁸⁴ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti, 55, 2010. (Port-au-Prince, 2010), 27.

⁸⁵ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic

Institutional Rebuilding:

It is important to physically rebuild the institutional buildings in Haiti and also the democratic system. The buildings act as symbols of Haiti's government and are the places that hold legislative functions. The earthquake created an opportunity for Haitians to strengthen their government system during the rebuilding efforts.⁸⁶

Haiti's Plan for Redevelopment:

The Action Plan for National Recovery and Development of Haiti will rebuild the country through three phases: the emergency phase, the implementation phase, and the recovery phase.

The emergency phase:

The emergency phase begins immediately after the earthquake, and responds to the most urgent and basic needs. These needs which are imperative to survival include shelter, food, and health. With the aid of international support, Haiti plans to address these requirements by providing temporary shelters, food, and portable toilets. It is also critical to quickly return children to school, create jobs for locals, and continue the democratic system by holding the next election. The emergency period will probably continue as long as there are people without shelter, food, or whose safety is compromised by the current conditions.

of Haiti, 55, 2010. (Port-au-Prince, 2010), 34.

⁸⁶ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic

The implementation phase:

The Implementation phase is the period in which Haiti will establish the goals that will dictate the territorial rebuilding, economic rebuilding, social rebuilding, and institutional rebuilding. This period is important to establishing the aspirations to create a better Haiti than before the earthquake, and will last about eighteen months.

The recovery phase:

The recovery phase is the period in which all the goals from the implementation phase are executed. The recovery period is a long term process where Haiti will continue to develop until it is a leading country by the desired date of 2030.⁸⁷

of Haiti, 55, 2010. (Port-au-Prince, 2010), 42.

⁸⁷ "Action Plan for National Recovery and Development of Haiti." edited by Government of the Republic of Haiti,

55, 2010. (Port-au-Prince, 2010), 42.

Chapter 9 - Seismic Design:

Building Form:

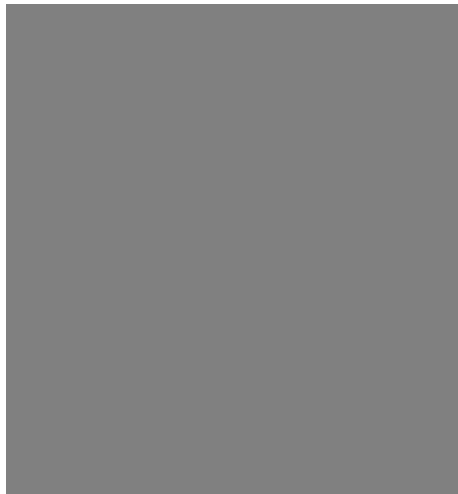


Figure 43 Whiplash effect on buildings (Schodek, 492)

The form of a building is important when designing to respond to seismic forces. A building with a low center of gravity has a shorter duration of resonance than a taller building. Fig 43 shows that when a taller building experiences sharp movement, the upper part of the building will follow the lower half. When the ground moves back in the opposite direction, the lower half of the building will move opposite to the upper half creating a “whiplash effect”.⁸⁸

⁸⁸ Daniel L. Schodek *Structures*. (Englewood Cliffs, N.J.: Prentice-Hall, 1980), 492.

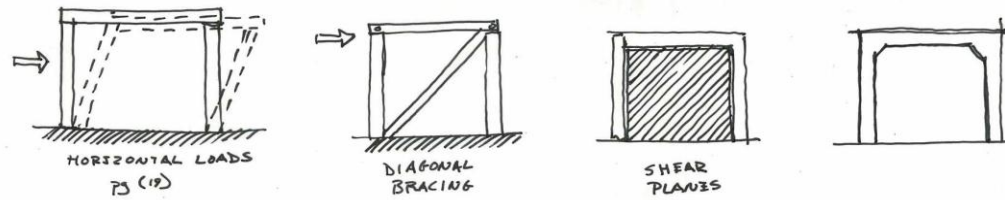


Figure 44 Diagram showing bracing technique (Ambrose, 58).

Lateral forces are the most common that induce stress on buildings during earthquakes. Different methods used to resist the lateral loads include diagonally bracing the structure, bracing the structure with a diaphragm, or making a rigid connection point (Fig. 44). Having a sturdy base is also important in resisting lateral forces.⁸⁹



Figure 45 Diagram showing non-symmetrical loading (Schodek, 494)

Symmetry in building forms is advantageous for resisting forces caused by earthquakes. The symmetry simplifies the calculations engineers use to evaluate the building's structure needed to resist the forces. Also, a lack of symmetry with regard to overall vertical stiffness can cause torsion. Fig 45 shows that a symmetrical building in form can be twisted without a balanced stiffness throughout the structure.⁹⁰

⁸⁹ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 58.

⁹⁰ Daniel L. Schodek *Structures*. (Englewood Cliffs, N.J.: Prentice-Hall, 1980), 494.



Figure 46 Diagram of Seismic Joint (Schodek, 494).

Having multiple masses in a building can create complexity when designing a connection that can resist seismic forces. Several methods that can alleviate the stresses between two structures are designing a joint that allows for independent movement of the masses, or by physically separating the two forms (Fig. 46).⁹¹

Concerning the structure, it is best to create an uninterrupted connection of the structural elements to the ground. Missing elements require additional support that can transfer the loads to another element: this becomes difficult under seismic forces.⁹²

⁹¹ Daniel L. Schodek *Structures*. (Englewood Cliffs, N.J.: Prentice-Hall, 1980), 493.

⁹² James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 58.

Chapter 10 - Materials:

A material's ability to successfully resist seismic forces depends on how much energy it can absorb without succumbing to permanent damage. Materials have different properties that determine how much stress and strain can be applied to it before deformation. Some materials such as steel and plastics have better elasticity and resilience, meaning that they can be subjected to greater forces before reaching their peak where damage occurs.⁹³

Wood Construction:

Light frame construction can be adapted to resist seismic forces with added support. The addition of vertical and horizontal diaphragms can be used to transfer lateral loads from structural components and into the ground. Plywood has strong shear resistance properties that make it ideal for added structural support in the form of a diaphragm. Fasteners are often required to secure the connection of different parts to resist seismic forces. Also, the size of the structural members may need to increase in order to withstand an earthquake.

A major challenge associated with light frame building is faults in the wood that structurally weaken the material. Also, there are many pieces that are a part of light frame construction requiring meticulously joining the parts.⁹⁴

⁹³ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 20.

⁹⁴ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 33.

Steel Frame Construction:

Steel frame construction is advantageous when resisting stresses because of the strength and flexibility that characterize steel. It is easily adaptable to different building types due to its structural properties.

However, common problems associated with steel construction with applied seismic forces are loosening of bolts, cracks in welded connections, and torsion in areas that are intensely loaded.

Optional solutions to resist lateral forces are diagonal bracing and moment resistant connections. It is feasible in smaller structures to strengthen the steel structure with shear walls made of different materials. Similarly to wood, steel structures consist of many parts that require careful assemblage, specifically if steel is being joined with a different material.⁹⁵

Concrete Construction:

Concrete can be problematic with seismic forces because of its vulnerability to tensile stress. Concrete is often used in collaboration with steel to help resist the tensile stresses. Concrete in general is susceptible to cracking caused by temperature changes and when shrinking occurs from curing. Exposure to seismic forces will result in grinding of the existing cracks, which can absorb some of the released energy, but can also be

⁹⁵ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 22.

permanently damaged, with too much grinding.⁹⁶

Precast concrete does not have as much structural continuity as on-site concrete construction. The typical steel connectors used to join precast pieces are insufficient for lateral forces. Precast concrete is also heavy and can bounce off the steel supports when exposed to vertical forces. Similar to wood and steel, precast concrete needs additional bracing with trusses or moment connectors.⁹⁷

⁹⁶ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 23.

⁹⁷ James E. Ambrose. *Seismic Design of Buildings*. (New York: Wiley, 1985), 38.

Chapter 11 - Program:

Conceptually, the location of a community center in a temporary neighborhood will allow a permanent neighborhood to evolve around a central core. Being a multi-functional space, the community center would conceivably create the notion of ownership that would be otherwise lacking in a hastily assembled neighborhood. By creating a prideful interactive space, the community center will unify the individuals, boosting the morale for other redevelopment projects associated with the earthquake.

The proposed thesis will investigate flexible spaces within the community center. This will allow Haitians to adapt the spaces based on their priority of needs. A space could potentially be a school during the week then transform into a market on weekend mornings. Another possibility would be for the transformation of spaces into an infirmary in the case of an emergency. A study will be conducted based on the feasibility of spaces to adapt to the current situation, based on dimensional issues. The initial investigations will look at the spatial qualities of a church, a market, a classroom, and a health center. These spaces will be compared with size as the dependent variable, allowing for the dimensional and spatial qualities to be consistently compared.

Additionally, using components as the primary construction technique will allow for various configurations of aggregated parts, and potential growth should the neighborhood flourish and further develop. It is important to allow for unique configurations of the community center since each disaster site will have a different situation, with different community needs, and different site qualities. The growth of the

neighborhood is feasible, since the proposed system of recovery for this thesis is investigating mass customization of parts, where consistently made components would enable expansion.

A Market:

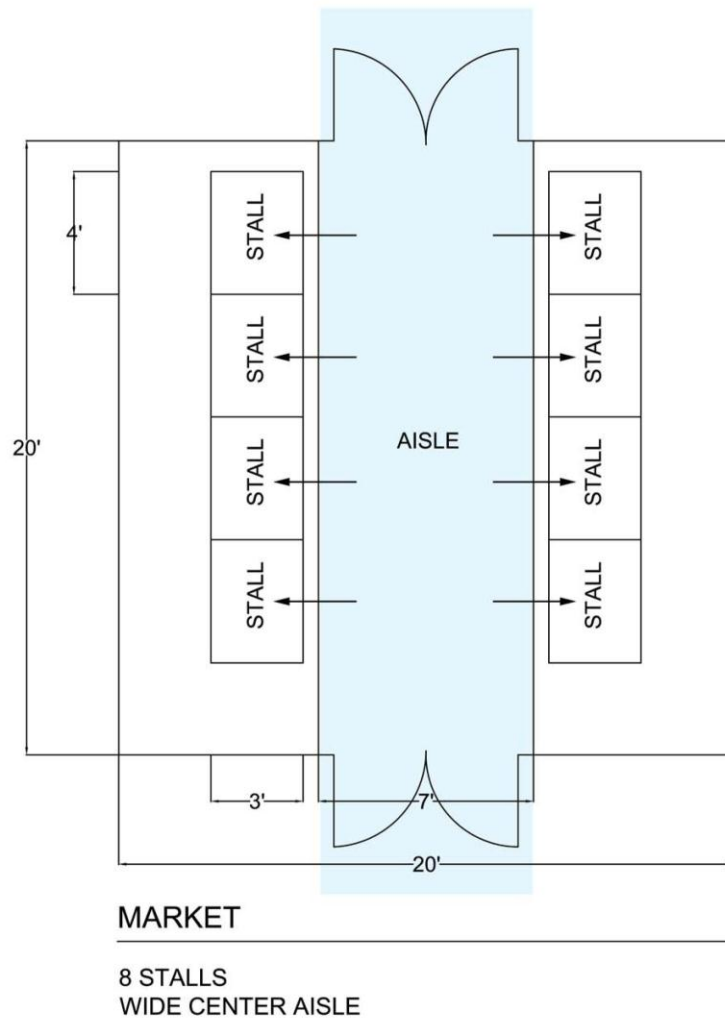


Figure 47 Dimensional qualities of a market in a 20' x 20' space.

During the investigation of a market, qualities of a supermarket were studied for

dimensional issues (Fig. 47). The needs of a market include a large center aisle enabling movement in multiple directions while shopping. Having a seven foot center aisle would allow for people to meander through the market space. The size of a market stall was compared to the size of an island in a supermarket. A market stall that is six feet by three feet would allow for the vendor to reach across the stall during interaction with the customer. Additionally, the vendor needs space behind his stall for standing to for his supplies. Fig. 47 shows a potential configuration of a market space.⁹⁸

⁹⁸ Joseph De Chiara, and Michael J. Crosbie. *Time-Saver Standards for Building Types*. 4th ed. (New York: McGraw-Hill, 2001), 117.

A Church:

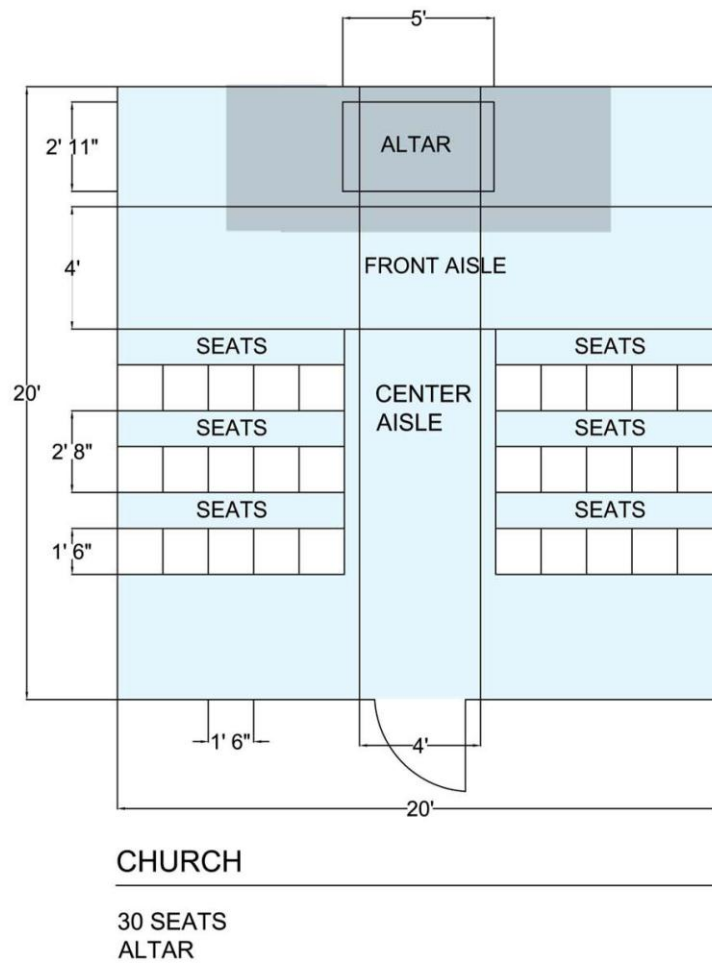


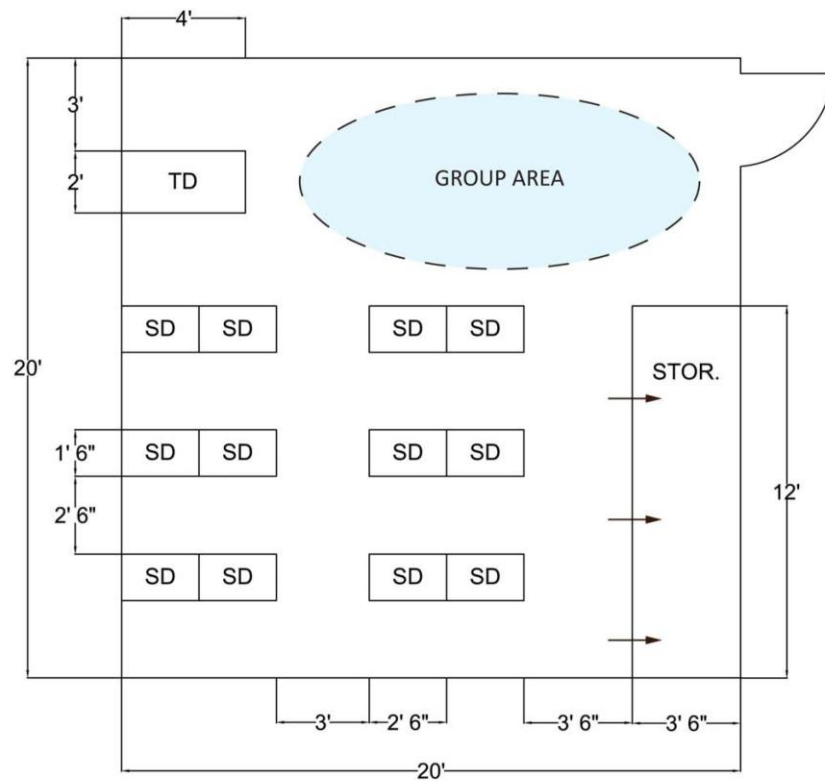
Figure 48 Dimensional qualities of a church in a 20' x 20' space.

While churches can be massed in various ways and consist of many social spaces, for the

purpose of this proposal, a simple rectangular shaped church will be used to investigate the dimensional relationships (Fig. 48). According to the Time Saver Standards for Building Types, a small church comprises of a center aisle of four feet, and a front and a back aisle of four feet. A church needs space for the altar and an altar platform. Additionally, individuals attending the church require about eighteen by eighteen inches of personal space at the pews.⁹⁹

⁹⁹ De Chiara, and Crosbie, 880.

A Classroom:



CLASSROOM

- 12 STUDENT DESKS
- 1 TEACHER'S DESK
- STORAGE SPACE

Figure 49 Dimensional qualities of a classroom in a 20' x 20' space.

Classrooms can be difficult to spatially plan for, since schools require spaces to learn in a

traditional setting where students face a blackboard, and for group learning (Fig. 49). There should be additional space allocated for storage, reconfiguration of desks, and because children do not confine to small spaces easily. Classrooms follow the accessibility codes of having three foot aisles. Desks will be approximately eighteen inches by thirty inches. Fig. 49 shows a possible layout for desks in a twenty by twenty foot space.¹⁰⁰

¹⁰⁰ De Chiara, and Crosbie, 388.

A Health Center:

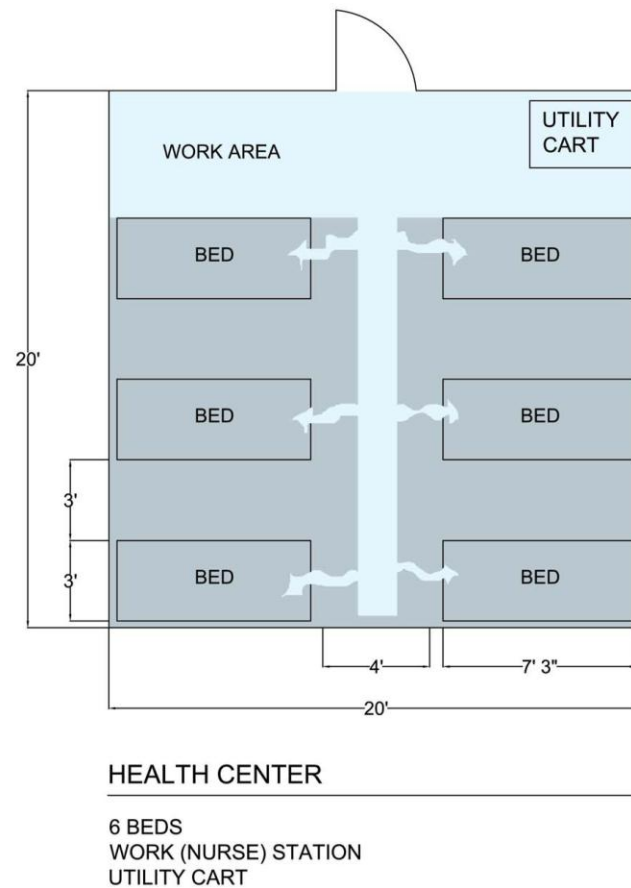


Figure 50 Dimensional qualities of a health center in a 20' x 20' space.

While health centers can be complex spaces, incorporating waiting rooms, preparatory rooms, cleaning rooms, surgical rooms, and recovery rooms, those spaces would not be suitable for a multi-functional community center (Fig. 50). The purpose of a potential

health center is for emergency situations, where room is needed for beds and a crash cart. According to the Time Saver Standards for Building Types, beds need three feet of space in between them, and four feet at the foot of the bed. However, during an emergency situation the space between beds would probably be reduced to allow for more people to inhabit the recovery space.¹⁰¹

¹⁰¹ De Chiara, and Crosbie, 522.

Part 3: Design Proposal

Chapter 12 – Design Concept:

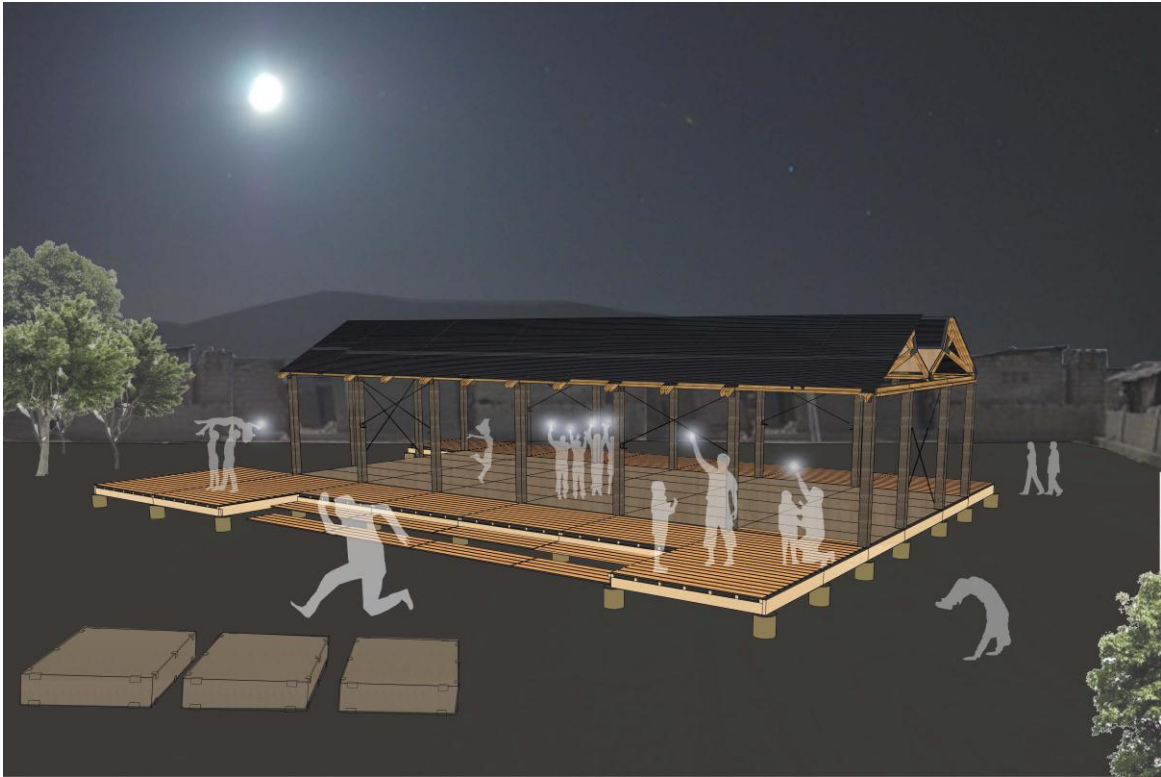


Figure 51 The process of community building will help bring people together.

Of the many solutions for disaster relief already in existence, the majority are not sustainable because they are perceived as temporary structures that do not fit into the local culture. Lacking in the physical product are elements of pride, ownership, and cultural adaptability. Responding to these issues, this thesis is about community building: everyday people, with everyday skills, using everyday tools. This creates the opportunity for the community to come together, to teach each other, and to build a community center. Even with many components prefabricated offsite, the physical product of the community center will probably not have the best craft. However,

community building will create a sense of ownership and pride for the final product that will establish the community center as a permanent cornerstone for the neighborhood.

Chapter 13 - System:

The emphasis of this project is not on the physical artifact that will be produced. This thesis is about the design of a system as described in Chapter 8. In addition to the physical design and construction of a community center, other factors will be designed such as the method of fabricating components, efficacy, the delivery of the components, handleability, and constructability.

Fabrication:

The advantages of prefabrication have been thoroughly researched in the first five chapters of this document. Prefabrication allows for components to be fabricated with better quality, in a faster manner, and cheaper than on-site construction. The components of the community center will be prefabricated to improve the quality of the end product. Also, it has to be assumed that the local people working on the community center are unskilled laborers, which means that customizing parts on site would be extremely difficult.

Efficacy:

Many disaster relief buildings are erected and built with as much speed as possible. This is often necessary to meet immediate needs; however, the results, although functional, are often unattractive structures that do not fit within the vernacular of the country. The goal of this system is to produce something that the local community can be proud of and that reflects their cultural identity. An example of this is the community center built in relief of Hurricane Katrina by Shop Architects, which provides an outside

porch that gives a place for the community to gather (Fig. 52).



Figure 52 Community center in response to Hurricane Katrina (shoparc.com). Accessed 05.05.11.

Delivery:

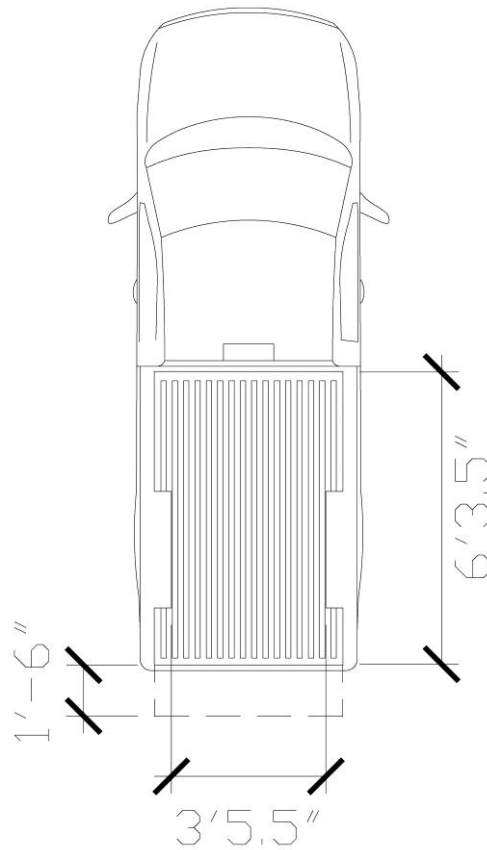


Figure 53 Truck dimensions for a Toyota Tacoma.

Another objective will be to detail the fastest method of transporting the materials from the location of the offsite factory to the location of the reconstruction efforts. Although circumstances may change based on the country and what is being delivered, ships and small trucks offer adequate solutions. Ships offer the potential to deliver multiple shipping containers at once so that only one trip would be necessary. The state of a country subsequent to a natural disaster is very unpredictable, so rail systems and

large trucks cannot be counted on for delivering the components. Standard pickup trucks are common and would have the best chance of maneuvering through the country. This involves the idea of modularization – designing the components to a size small enough to fit in any everyday vehicle. The cheapest truck in 2010 had a base price of \$15,345.¹⁰² The dimensions of the truck's bed are 41.5" wide and 73.5" long (Fig. 53).¹⁰³ Most everyday trucks will generally be close to this size or a little larger. Pickup trucks are also vehicles that are rugged in design, so they would be perfect to maneuver through debris left by natural disasters.

¹⁰² "Best Cars." U.S. News, < http://usnews.rankingsandreviews.com/cars-trucks/Toyota_Tacoma/2010/> 05 May 2011

¹⁰³ Toyota, <<http://www.toyota.com/tacoma/specs.html>> 05 May 2011

Handleability:



Figure 54 Large machines cannot be counted on for construction.



Figure 55 Components should be constructed to easily be handled with only man-power.

The unpredictable circumstances of a country following a natural disaster also have an effect on the construction process. Since there is a possibility that there will be no large machines available to aid with construction, it is necessary to fabricate the components to

easily be handled using only man-power.

Constructability:



Figure 56 Simple hand tools
(http://www.google.com/imgres?imgurl=http://images.businessweek.com/di/idea_winners/2007/oxo_handtools.jpg). Accessed 05.05.11.

The majority of the people constructing the community center will be unskilled laborers. The lack of experience makes it important to simplify the assembly process and create simple connections so that “everyday” people would have the capabilities to construct the community center using standard tools. This will have an effect on the materials used. Many masonry buildings were destroyed in Haiti due to the lack of skills that are required to construct a quality masonry building. Also, construction using a material such as adobe brick would require large machines that are unfamiliar to most people. Metals are also not a common material used and would complicate assembly.

Chapter 14 – Site:

Although much inspiration stemmed from the horrific events that occurred in Haiti in 2010, the project does not intend to limit its scope to only Haiti. Countries' responses to natural disasters are all similar; consisting of three overlapping phases of immediate, short term and long term goals, comparable to Haiti's action plan described in chapter 9. The similarity in responses to the natural disasters allows for the proposed system to be implemented in different countries. The design objective for the proposed system of relief is to respond to the emergency phase, the implementation phase, and the reconstruction phase of this action plan.

In theory, the proposed design of a system for disaster relief could be applied to any country, and any climate. The idea of cultural and climatic adaptability is a concept that will continually be investigated past this thesis project. For the sake of the time restraints on this thesis, parameters were created limiting investigation to tropical climates, which are most commonly subjected to natural disasters. The resulting physical artifact of this project will be responding to specifically earthquakes, strong winds, and the heat and water of tropical climates.

Earthquakes:



Figure 57 Diagram of Seismic Joint (Schodek, 494).

In response to earthquakes, the goal of the design for the community center is to create a symmetrical design. The loading, the bracing, and the massing should be symmetrical to avoid torsion (Fig. 57).¹⁰⁴ Based on the research done in Chapter 10 on seismic design, the objective is to keep the design as simple as possible.

¹⁰⁴ Daniel L. Schodek *Structures*. (Englewood Cliffs, N.J.: Prentice-Hall, 1980), 494.

Strong Winds:

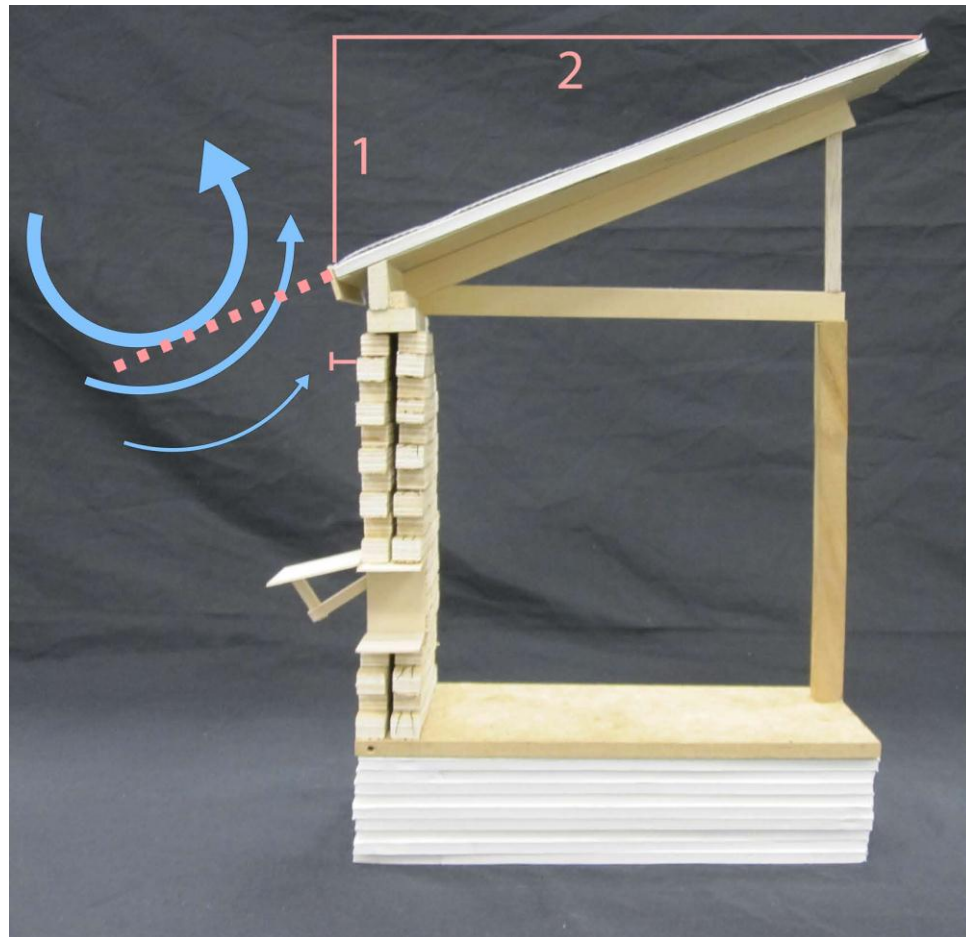


Figure 58 Wall section responding to strong winds.

In response to strong winds, it will be important to keep all elements of the community center close to the building. This is important because objects that are extruded past the walls have a better chance of being ripped off from wind uplift (Fig. 58). Also, the ideal slope of a roof for strong winds is 1:2.¹⁰⁵

¹⁰⁵ Architecture for Humanity, “Rebuilding 101 Manual.” March 2010.
http://openarchitecturenetwork.org/sites/default/files/active/18/rebuilding101_en.pdf (Accessed May 7, 2011).

Water Management:



Figure 59 Elevating the building on concrete piles will protect it against small floods.



Figure 60 The method of draining water is critical in tropical countries.

In tropical countries, rain creates another performance criteria for architecture.

The proposed community center will be responding to light flooding, meaning the building will probably be raised up on concrete piles to elevate it above the flooding (Fig. 59).¹⁰⁶ Additionally, with a lot of rain the building needs to have a system of drainage to

¹⁰⁶ http://openarchitecturenetwork.org/sites/default/files/active/18/rebuilding101_en.pdf

direct the water (Fig. 60).

Heat Prevention:

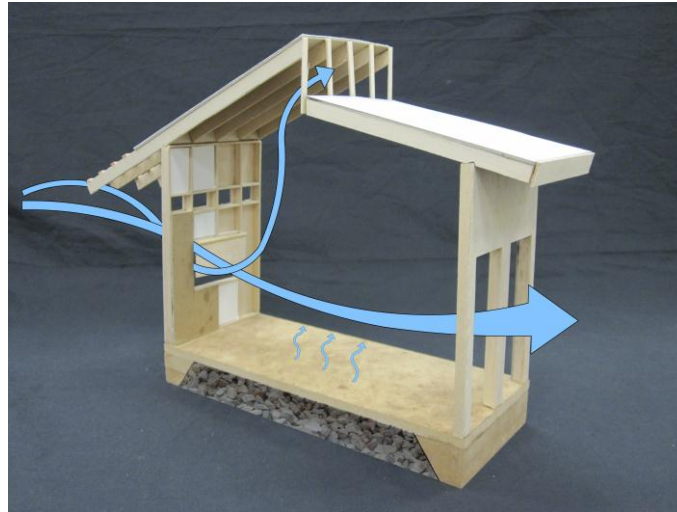


Figure 61 Maximizing air flow.

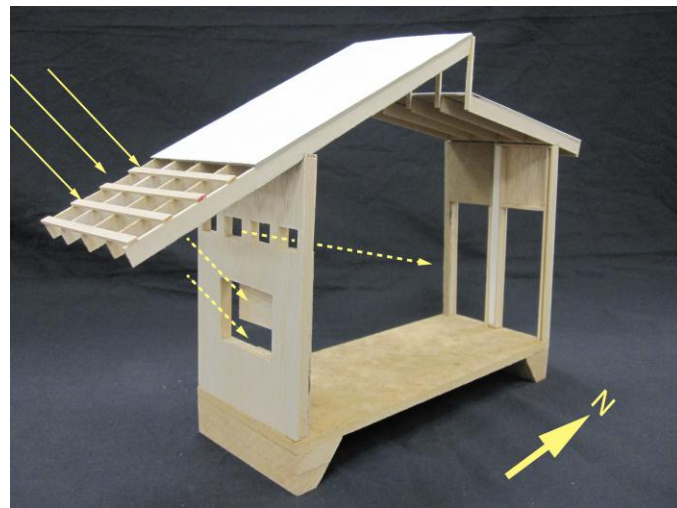


Figure 62 Blocking direct sunlight.

Minimizing heat is critical in hot-humid tropical climates. One important strategy to reducing heat gain is by maximizing air flow. To increase the velocity of the air movement, a smaller opening should be placed on the windward side opposite of a larger opening on the leeward side (Fig. 61). Creating air movement is also important to

prevent stagnant air.¹⁰⁷

It is also important to block any direct sunlight to minimize heat gain. It is better to let light in indirectly, which will also help prevent glare (Fig. 62). Trellises, awnings and louvers are all methods that can be used to prevent the direct sunlight.¹⁰⁸ Using wood for the community center will help minimize heat gain since it is a light material that will not act as a thermal mass and capture heat.

¹⁰⁷ Cleveland Salmon, *Architectural Design for Tropical Regions*. (New York, NY: John Wiley & Sons, Inc., 1999), 142

¹⁰⁸ Salmon, 145.

Chapter 15 – The Shipping Box:

The genesis of the concept for the community center derives from the idea of shipping boxes. Shipping boxes come in a variety of sizes and are used to deliver materials to another country. After the boxes arrive at the destination, the boxes are often thrown away. The proposal for this community center, instead, has the boxes being recycled as part of the construction of the building. This in effect will:

- Minimize waste
- Respond to all three phases of the action plan discussed in Chapter 9
- Create a culturally adaptive community center

Minimizing Waste:

The boxes, instead of being thrown away after their initial function of delivering materials, will become the skin and structure of the building's walls. These boxes will be customized and prefabricated. The lids of the boxes will be made to function as hurricane shutters.

Response to Action Plan:

The shipping boxes will be used to transport all the basic human needs as described in the action plan. These necessities will include food, clothing, and basic sanitation. After the boxes are emptied, they will be used as the walls of the community center; creating a permanent structure in response to the implementation and

reconstruction phase of the action plan.

Culturally Adaptive:

With the boxes used as the walls of the community center, they will create niches along the perimeter of the building that can be filled with any vernacular materials or objects local to the region. This will transform the community center from a prefabricated structure into a customizable gathering space, creating a sense of ownership and pride from within the community.

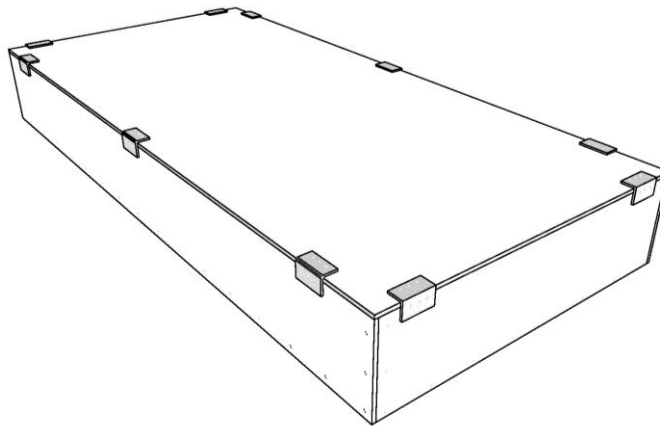


Figure 63 Shipping Box

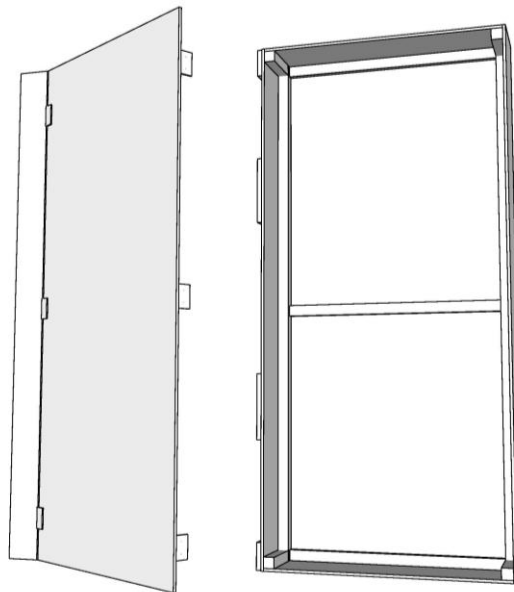


Figure 64 Shipping box becomes part of the wall.

The shipping boxes are 3ft 9in to fit in between the columns, and either 8ft or 4ft long. The lid of the 8ft boxes becomes a door (Fig. 64) and the lid of the 4ft boxes become hurricane shutters. The boxes are made this size to optimize handleability and delivery. They are small enough to be transported with a pickup truck and handled by

one or two people during construction of the walls.

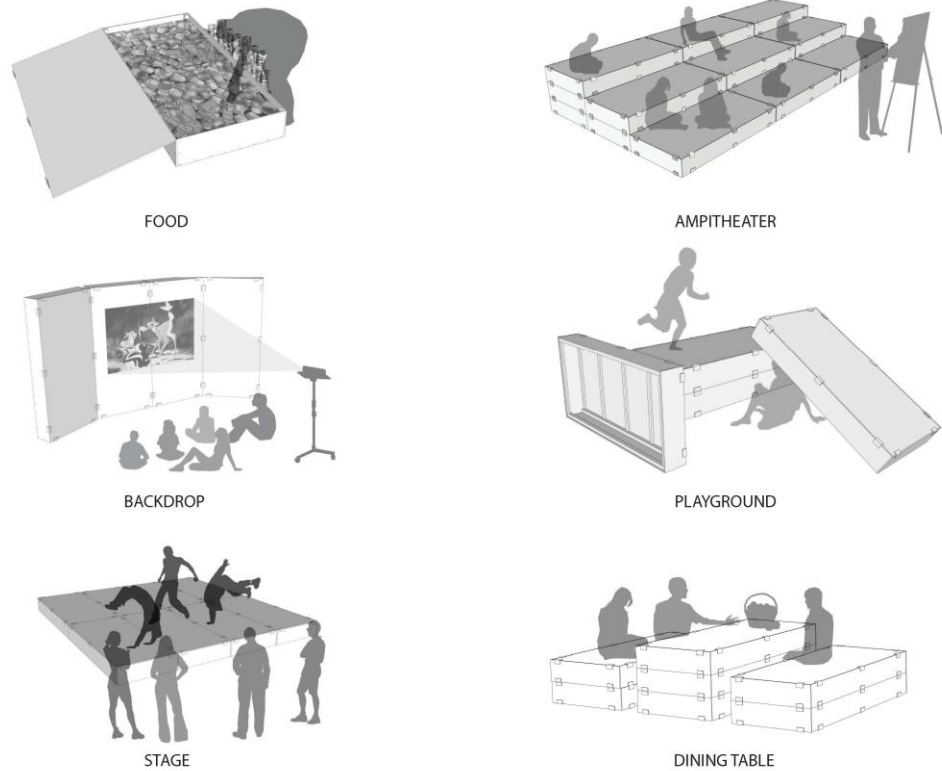


Figure 65 Activities with shipping boxes.

The shipping boxes can be used in a variety of different ways during the construction process before the walls get built (Fig. 65).

Chapter 16 – Construction Details:

Floor Systems:

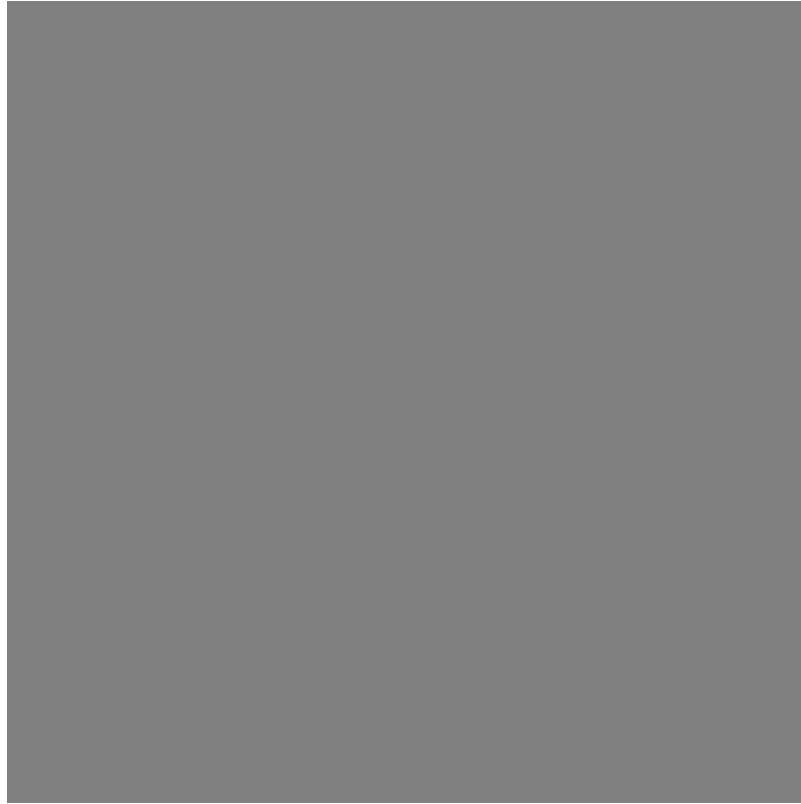


Figure 66 Concrete form tube from Home Depot (homedepot.com). Accessed 05.07.11.

The foundations are constructed by placing Sonotubes into holes dug in the ground. Sonotubes are made of cardboard and function as formwork for poured concrete. This is a cheap and available option; a twelve inch diameter tube that is four feet long is only \$10.30 at Home Depot.¹⁰⁹

¹⁰⁹ www.homedepot.com (Accessed May 7, 2011).

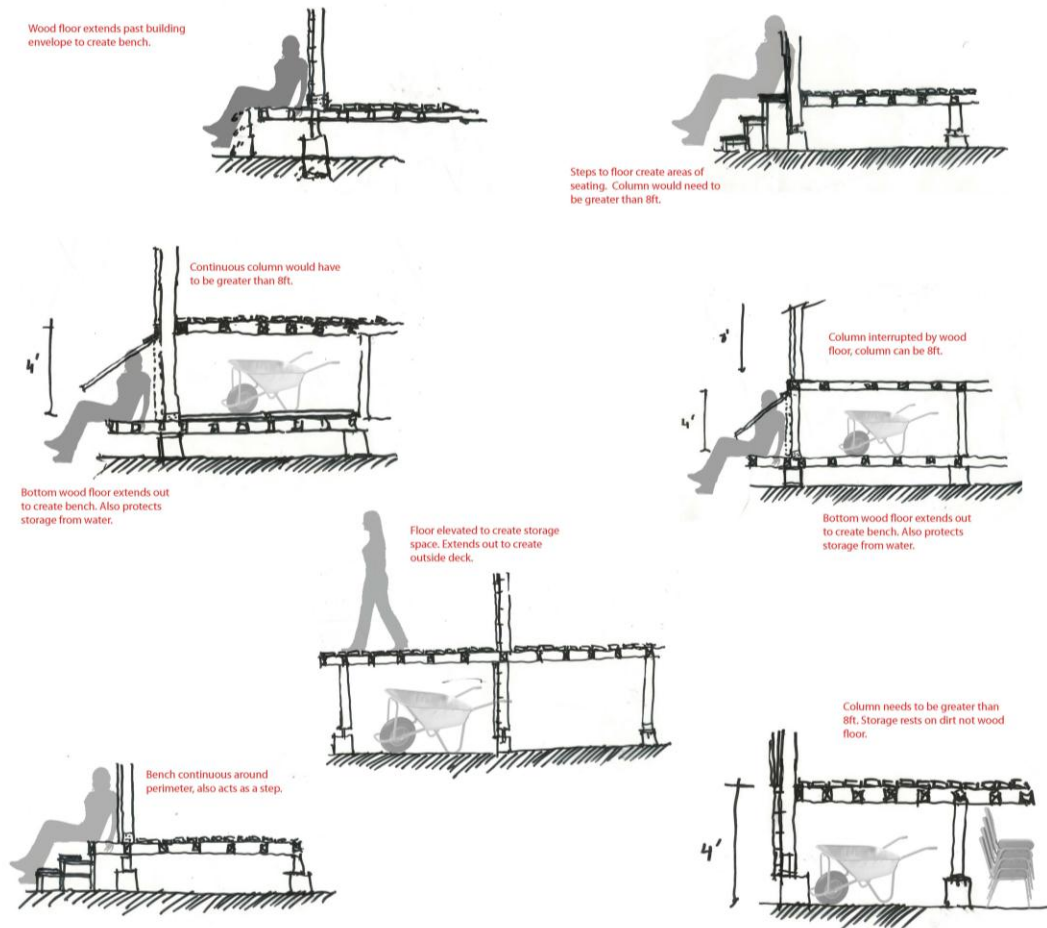


Figure 67 Floor systems.

Different methods of framing the floor were investigated. Based on the height that the floor was elevated off the ground and how far the floor plane extended past the walls dictated elements such as storage room and creating seating areas (Fig. 67). Two options were explored where either the column met the foundation, or where the column rested on the floor plane. For reasons of connection and strength, the option was chosen to have the column meet the foundation (Fig. 68). The option used for the design of the

community center was the image on the top right of figure 67. The floor plane is elevated eighteen inches off the ground to create seating areas around the perimeter of the building.

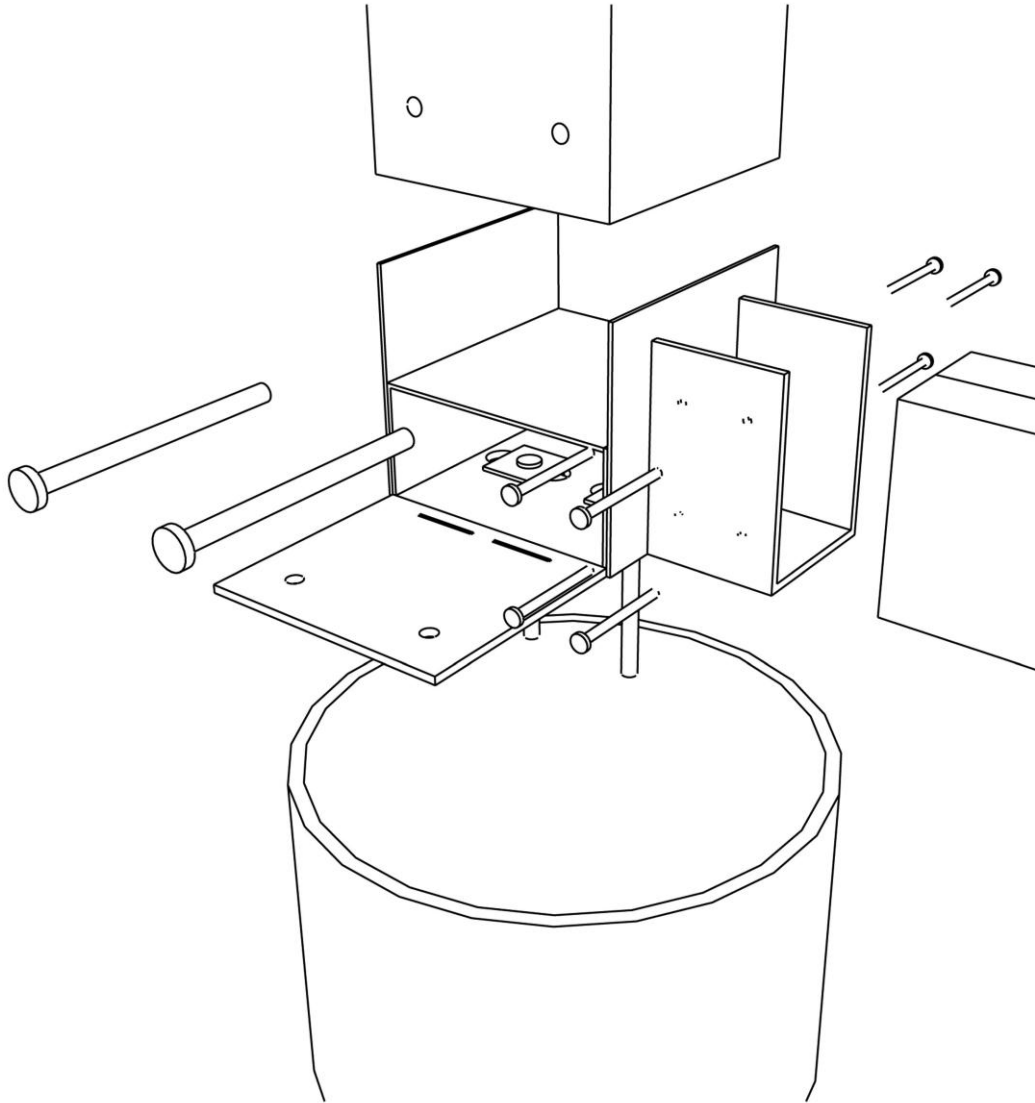


Figure 68 Connection of column to foundation.

Wall Systems:

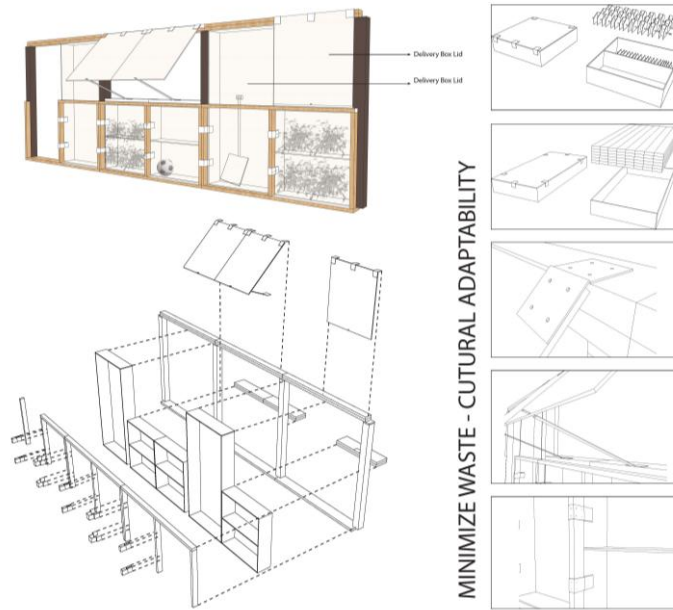


Figure 69 Option 1. Wall System – Cultural Adaptability

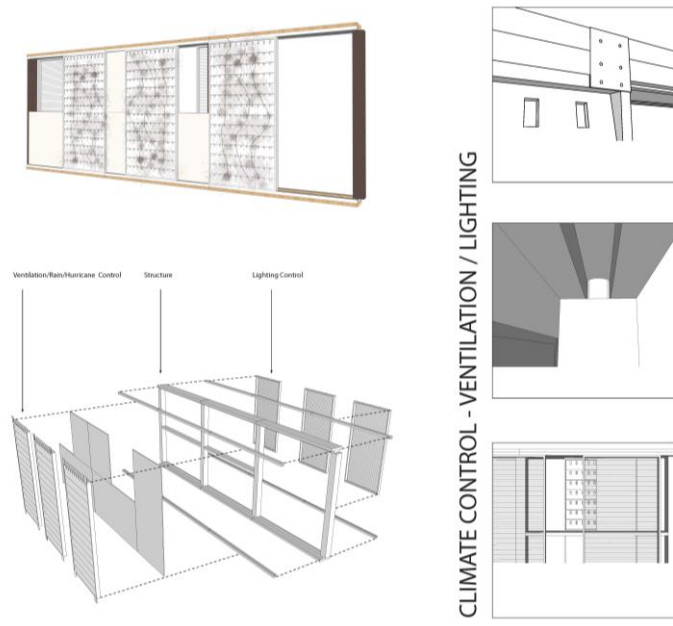


Figure 70 Option 2. Wall System – Climate Control

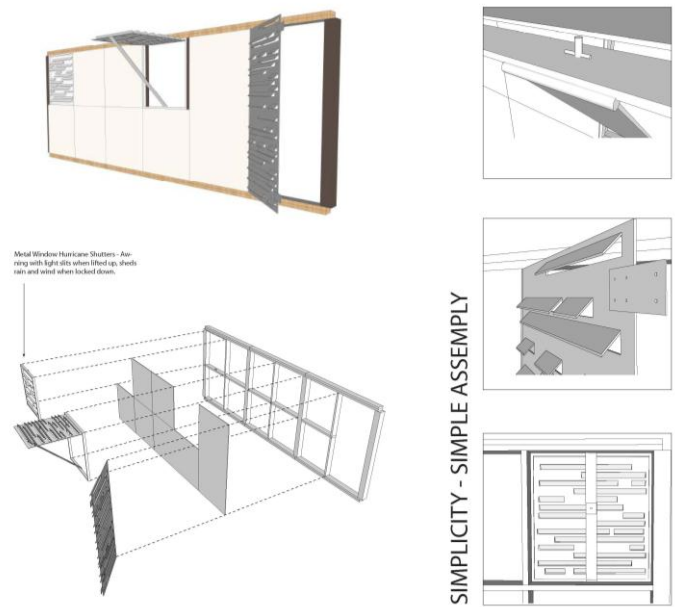


Figure 71 Option 3. Wall System - Simple Assembly

Different wall systems were explored in relation to cultural adaptability, climate control, and simple assembly. Option 1 was the best, since it combined elements of all three factors. In regards to cultural adaptability, the shipping boxes create niches in the wall that can be filled with local materials. In regards to climate control, the lid of the shipping boxes can be used as hurricane shutters and awnings to block high winds and sun. Finally, since the boxes come as modules of approximately 8ft x 4ft and 4ft x 4ft, they can easily be nailed together between the structures (Fig. 69).

Truss/Rafter System:

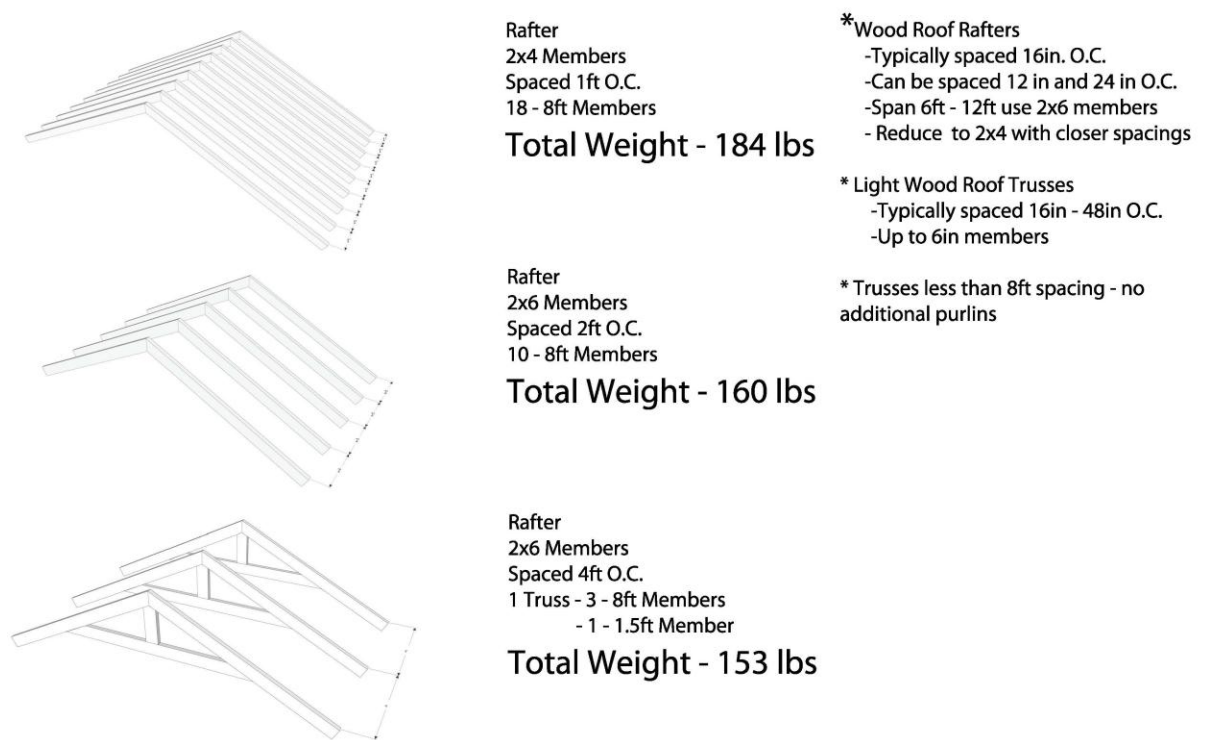


Figure 72 Weight comparison of truss and rafters.

An analysis was done to compare the total weight and number of members needed for a rafter and truss system. The first rafter option is comprised of members spaced 12in off-center. The members for option 1 are 2x4in dimensional lumber, and can be this small because the members are spaced so close together. One bay consists of eighteen members for a total weight of 184lbs.

The second rafter option consists of members spaced 24in off-center with 2x6 members. Only ten members are needed for the bay with a total weight of only 160lbs.

Finally, the third option comprises of three trusses spaced 4ft off-center with

2x6in members for a total weight of 153lbs. This analysis helped determine that a truss system would be used for the community center.

The members of the truss would also be a maximum of 8ft. Modularizing these components would help the pieces fit in smaller trucks, making the delivery process easier.

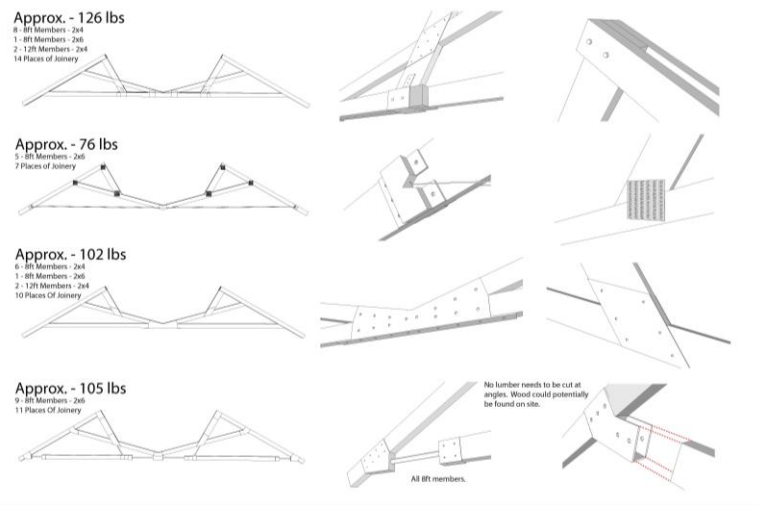


Figure 73 Option 1. Truss/Rafter

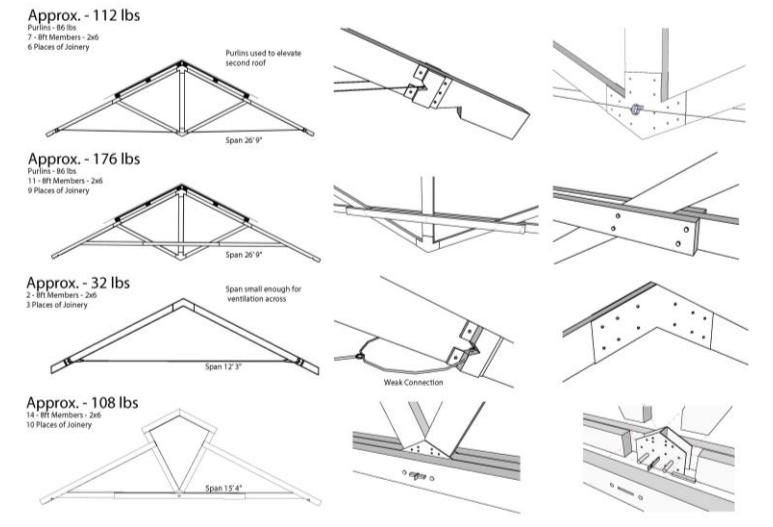


Figure 74 Option 2. Truss/Rafter

When exploring the shape and form of the truss or rafter system, the two major factors that were considered were ventilation and drainage. In response to these factors, Option 1 was the best since it created two areas of ventilation, and since the butterfly shape created a draining system that anyone can easily understand (Fig. 73). The water is collected in the middle and diverted to a cistern on the end. This creates the perception of a well acting as a gathering place for the community center.

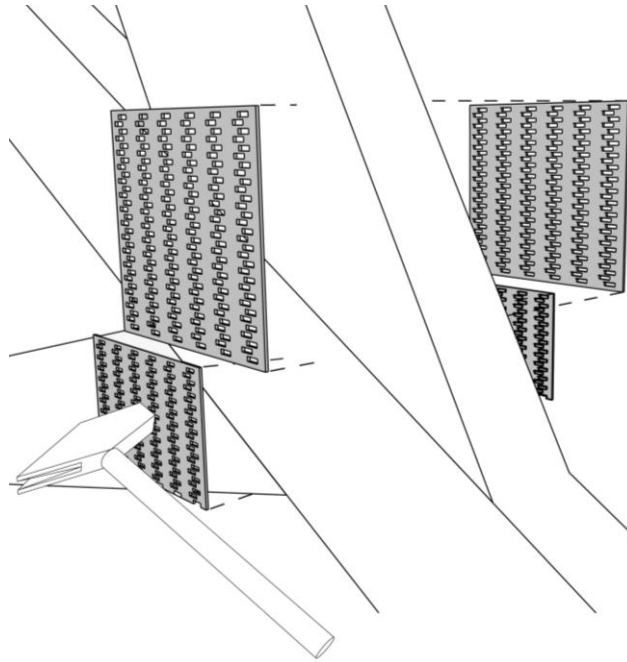


Figure 75 SIMPSON Strong-Tie metal plate

Different connection types and assembly methods were also studied to determine how to best construct the truss (Fig. 73). In regards to constructability, an easy connection type is using a metal plate that does not require a high level of accuracy. SIMPSON Strong-Tie is a company that sells metal fasteners, screws, tie-down pieces, and fasteners. A particular product of theirs is a metal plate that can be used to connect two pieces of wood. The metal plate has many small metal points that act as nails when hammering it into wood (Fig. 75).

Roof:

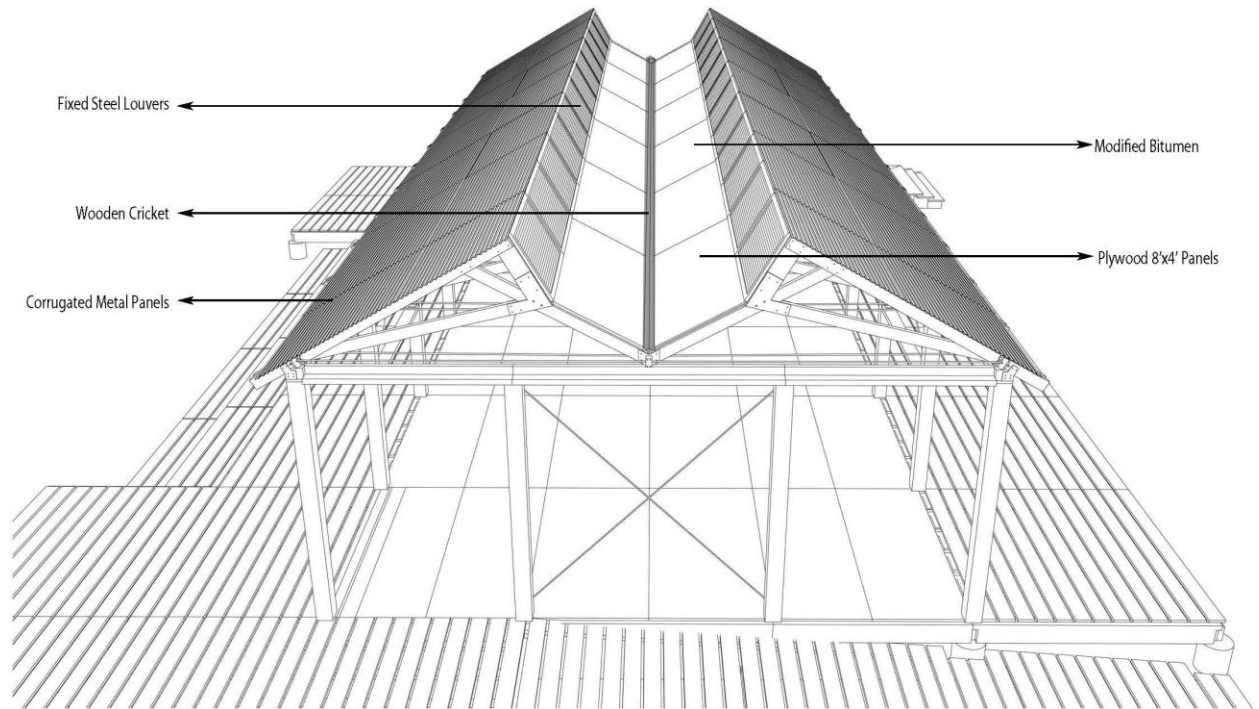


Figure 76 Roof materials.

The roof is made of a few materials responding to climate, handleability and delivery. Corrugated metal roof panels and pieces of plywood are made in 8ft x 4ft modules, which is small enough to fit in a pickup truck if needed. The corrugated metal panels are used on the outside slopes since they are light weight and waterproof. The metal does not act as a thermal mass, reducing the heat inside the building. Plywood is used in the valley of the butterfly roof to create a flat area for an extra layer of waterproofing. A good solution for waterproofing the roof is modified bitumen, which has rubber-like properties that can protect it against water (Fig. 76).¹¹⁰

¹¹⁰ www.tremcoroofing.com (Accessed May 8, 2011).

Chapter 17 - The Community Center:

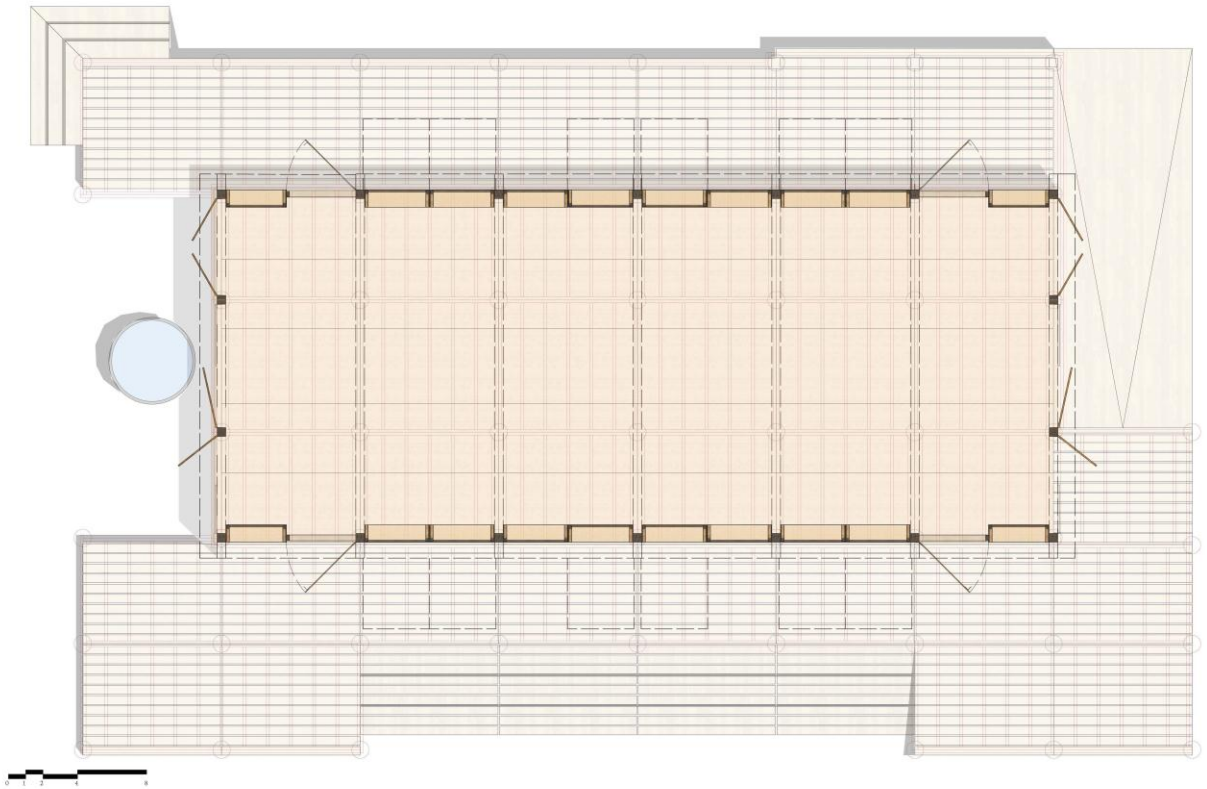


Figure 77 Plan of the community center.

The plan of the community center is formed to create a flexible open space allowing for a variety of activities. To achieve this quality of flexibility, the trusses span twenty feet leaving the interior completely free of columns. There are two entrances on both the north and south side, and the wall panels on the east and west walls swing out for ventilation. The Community center is 48ft long and 20ft wide.

The boxes defining the perimeter of the space face both the interior and exterior to create opportunities to customize the façade that will be viewed by the community, and to function as storage space or shelves for the inside activities.

Aggregation:

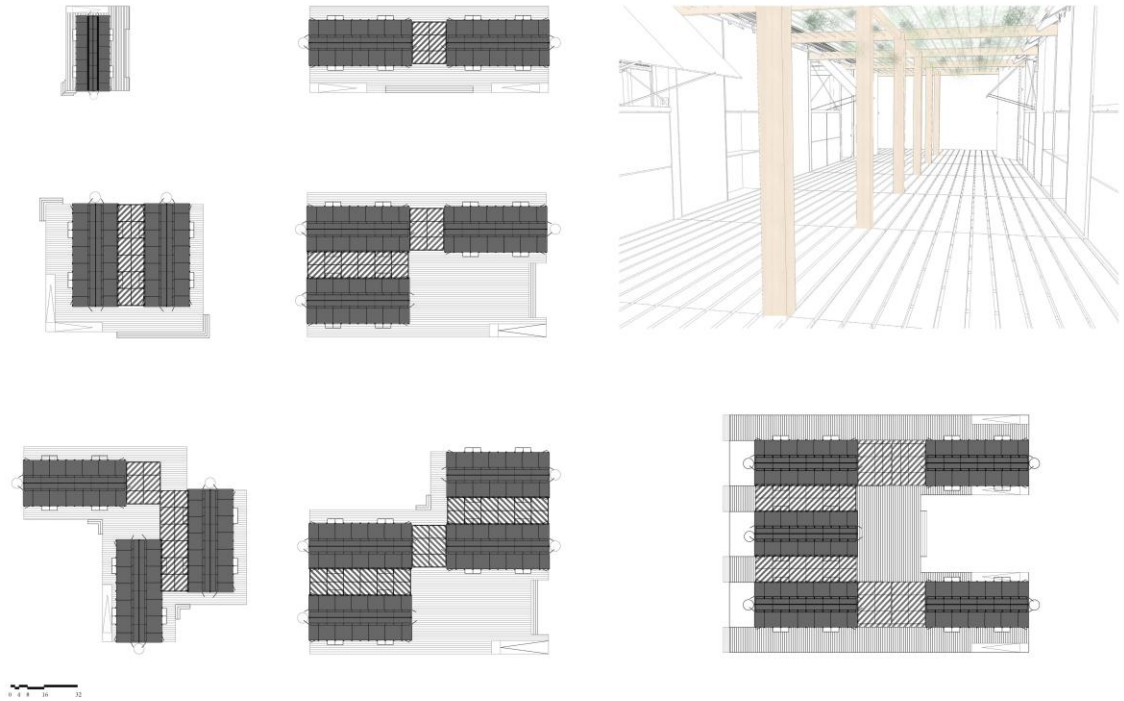


Figure 78 Possible aggregation of buildings.

While one building creates a flexible space for multiple functions, the building modules can aggregate together to create a larger community. There is additional flexibility in the different combinations of formations to accommodate for the context or a specific vision of the community. A common language was designed as the transition between buildings; a trellis covers the area to create a covered space acting as an extension of the interior space (Fig. 78). Two buildings could potentially open up onto the trellis and create an even larger space (Fig. 79). The use of a common language to connect to buildings offers the chance for future growth of the community center over time.

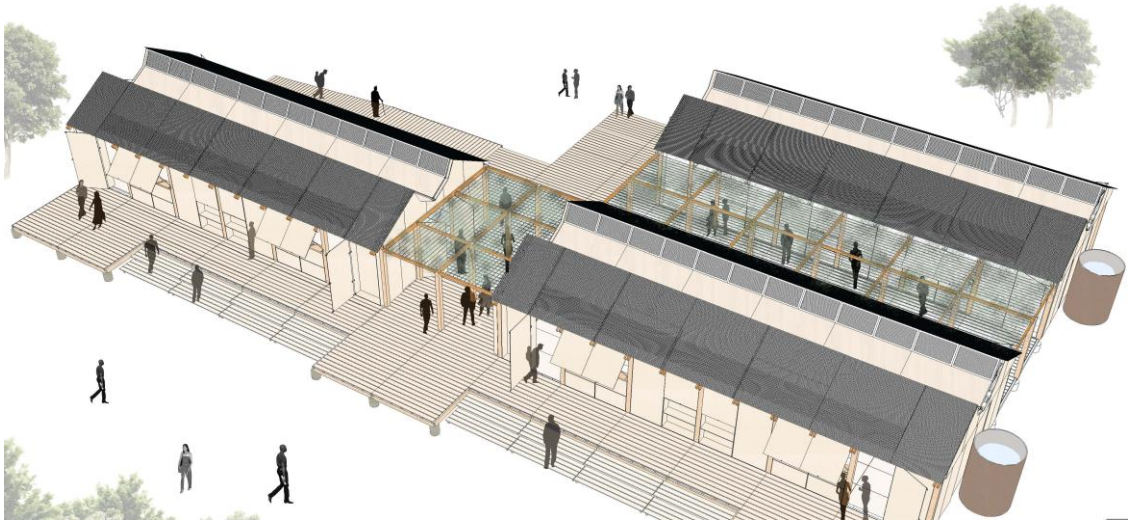


Figure 79 Perspective of community center.



Figure 80 Community center in context.

Figure 80 shows hypothetical aggregation combinations of the community center within a region of Haiti. The earthquake that hit Haiti in 2010 left some regions in poor conditions. The flexibility of the different community center formations offers the potential to fit them in different open spaces throughout the community. Ideally the city could evolve around the placement of the community center.

Chapter 18 - Timeline (8 Week Life of Recovery System):

Day 1



Figure 81 Basic human needs are collected and sent to "Country X" in shipping boxes (www.thegreenestdollar.com). Accessed 05.08.11.

- A disaster hits "Country X."
- Responding agency contacts "Country X" for project planning.
- Responding agency is working with a charity (Red Cross, AmeriCares, etc) and starts collecting human essentials such as food, clothes, and sanitation needs.
- Factory starts prefabricating shipping boxes and other building parts.

Week 1

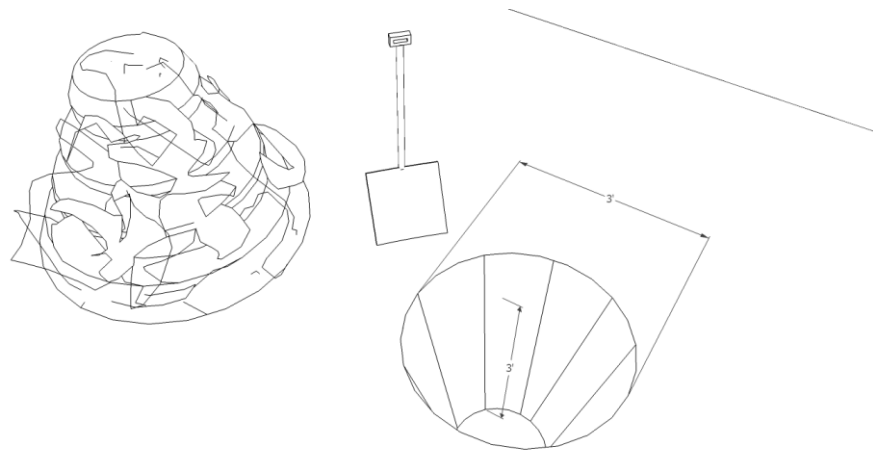


Figure 82 Digging holes for foundation.

- “Country X” can start digging the foundation holes.

Week 3

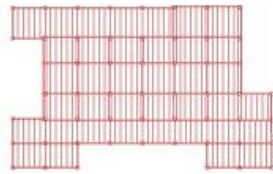


Figure 83 Shipping containers will deliver all the supplies at one time to "Country X" (www.containersavings.com). Accessed 05.08.11.

- Responding agency delivers shipping boxes and building parts to “Country X.”
- After sending supplies, the responding agency can contact the second location of

priority for reconstruction.

Week 5



1 Bldg - 55 Sonotubes



Approx. 30 min to mix and fill Sonotube



5 people working

1 Day

24 Hrs for curing

2 Days Total

- “Country X” starts construction of foundation. The minimum number of Sonotubes needed for one building is fifty-five.
- Based on personal tests of pouring concrete into Sonotubes, it can be estimated that each tube could be filled in thirty minutes. With the assumption that the community is working together, the concrete could be poured in one day, plus an

additional day for the concrete to cure.

Week 5 – 6

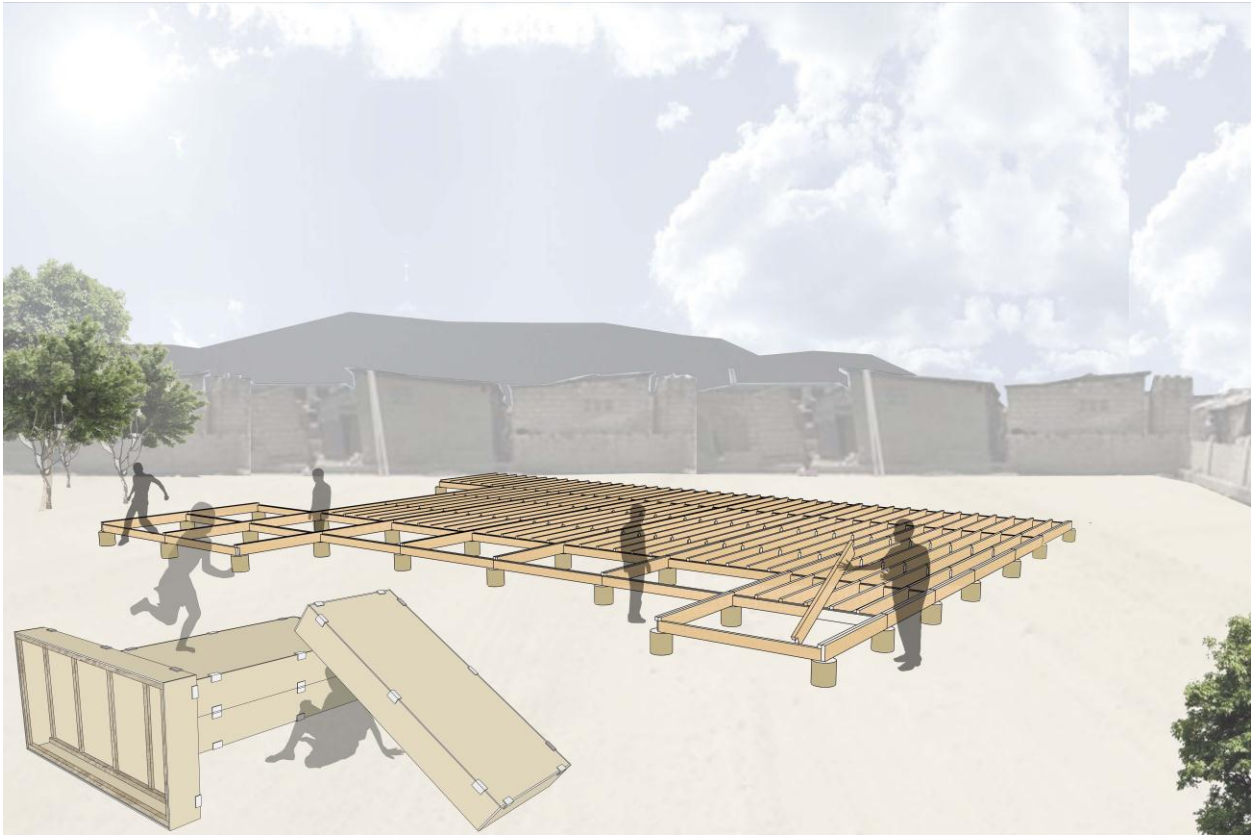


Figure 84 Framing of the floor.

- Framing of the floor will take approximately one week.
- Shipping boxes can be used as outside activities until the construction of walls.

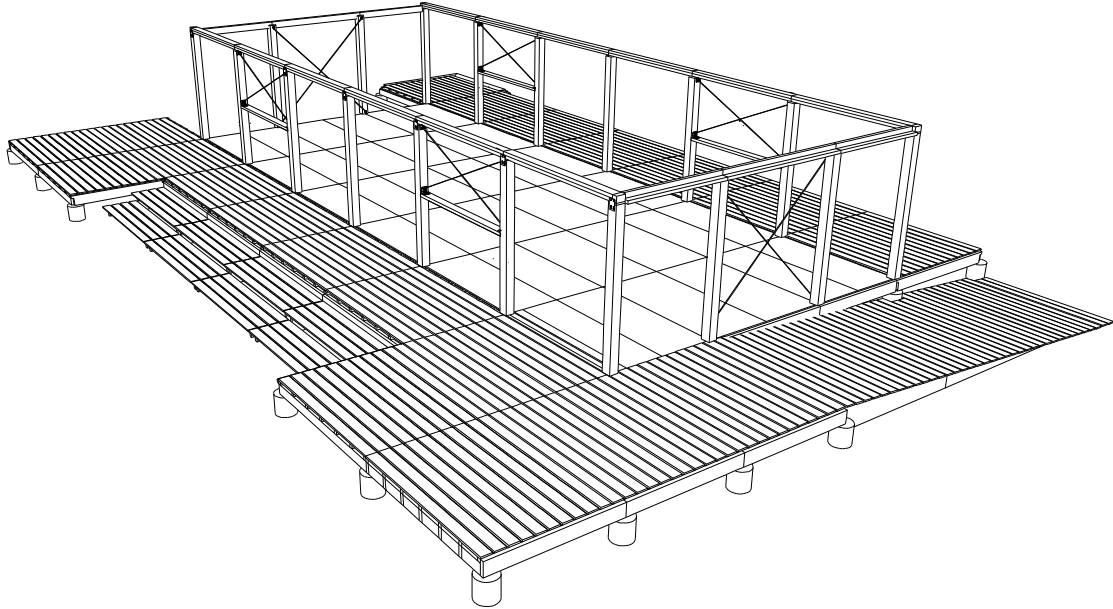


Figure 85 Framing and the trusses are worked on simultaneously.

- The framing and the truss construction are fabricated simultaneously so that the trusses can help stabilize the structure.
- Based on personal tests of constructing a truss, it can be estimated that one truss with prefabricated parts would only take about one hour. With thirteen trusses in one building, the trusses can be fabricated in only one day.
- Construction of framing could be fabricated in approximately two days.

Week 7

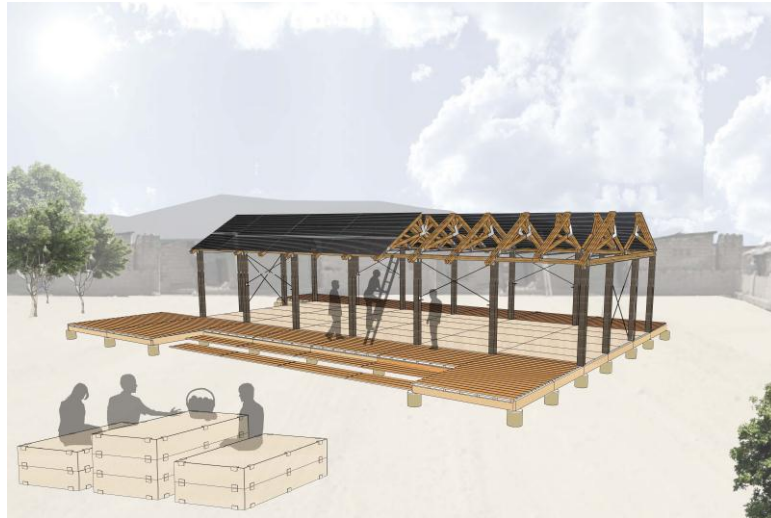


Figure 86 Roof construction.

- The laying of the plywood panels, corrugated metal roof panels, modified bitumen, and wooden cricket can be finished in one day.



Figure 87 Wall construction.

- The shipping boxes can easily be nailed into the framing in one day since they are prefabricated at a modular size.

Week 8



- Building is completed.

Chapter 19 - Human Experience:

This thesis proposal was focused on a system for reconstruction. Essentially, however, the system was designed to improve the life of humans, meaning the system does not work if it does not create a positive experience for people. This human experience is the underlying qualitative factor for most projects.

Given the open flexible space of the community center and the niches in the wall created from the shipping boxes, three example activities that could occupy the space are a church, school, and marketplace.



Figure 88 Community center being used as a church.

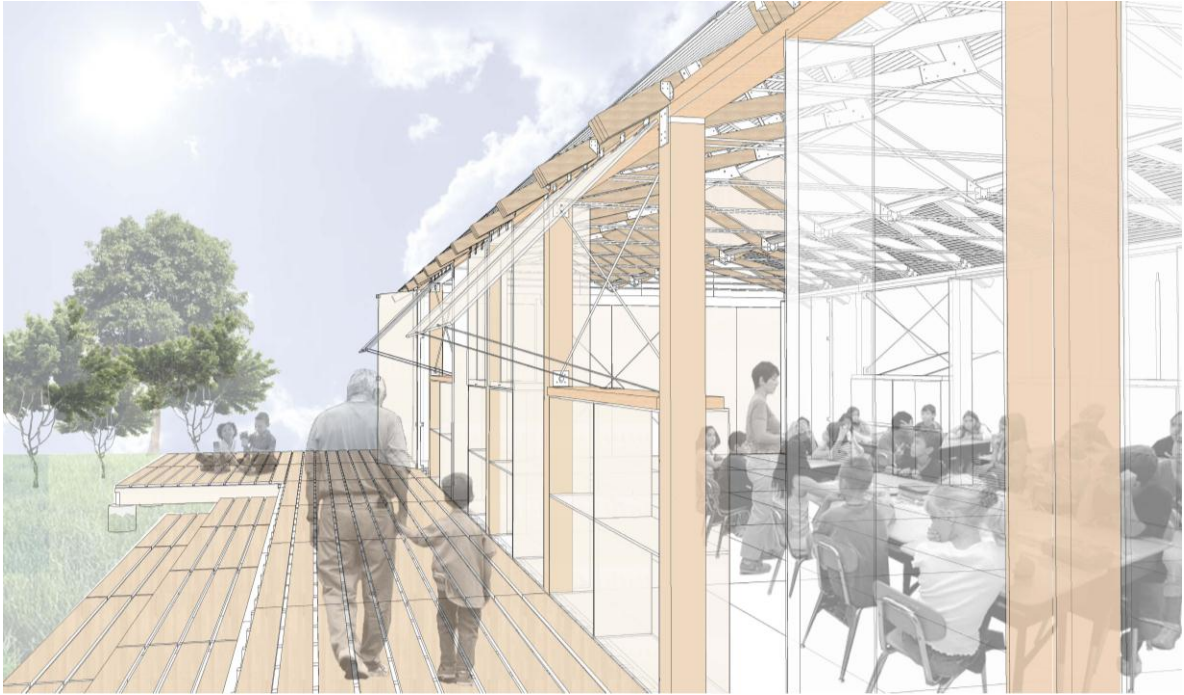


Figure 89 Community center being used as a classroom.

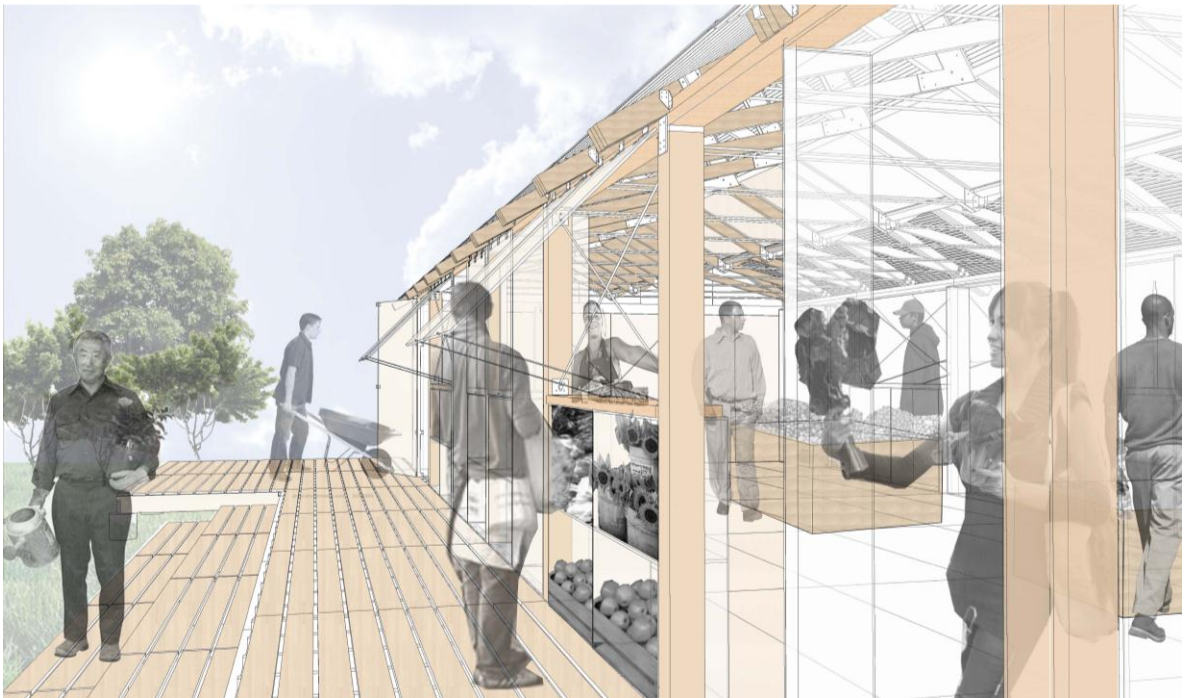


Figure 90 Community center being used as a market.

Chapter 20 - Conclusion:

Highlighted in this thesis is symmetry between the ideas and the process of getting to these ideas. The proposal emphasizes a “system” of disaster relief instead of the physical artifact, mirroring how working on this project is more about the process than the final product.

The initial ideas of this thesis began from the intrigue of prefabrication. Time was spent researching different case studies, advantages, and opportunities of prefabrication. However, after the first design review it was clear that a program was necessary to apply the ideas of prefabrication.

Earlier that year, the world had seen the unfortunate consequences of the earthquake in Haiti. In response to the earthquake, there were many attempts at disaster relief shelters using prefabrication. With a lack of concentration at the community level, it sparked the idea of using prefabrication that could service a whole neighborhood instead of individual houses.

Although the idea for this thesis was originally about prefabrication, the project began evolving to focus on a whole system of disaster relief. This system included prefabrication, but also comprised of issues of efficacy, delivery, handleability, and constructability as discussed in previous chapters. The goal was to design a culturally adaptive system that could respond to disasters in many different countries.

One of the major themes of this thesis that drove this project from the beginning was designing at the detail level and understanding the tectonics of making. By focusing

attention on building assembly, this thesis continues an interest in design details that started at the beginning of graduate school. This theme of working at the level of the detail became a large part of the project's process, and was also very humbling to recognize the lack of understanding that graduate students have in regards to the construction process. However, concentrating on tectonics has strengthened knowledge on this subject, becoming a bridge to professional practice.

Models were often a tool used to explore the ideas of constructability and scale during this process. Full scale models were constructed and although they changed during the process, they helped inform design decisions in regards to connection types and their overall form.



Figure 91 Full scale model of foundation, base plate, and column.

During the public presentation of this thesis, there were helpful discussions that will help with the advancement of these ideas. One comment questioned wood as the main material. This questions the idea of using a vernacular material to the region and whether a local factory should be erected for this disaster relief system. However, the system designed for this thesis responds to a disaster after it happens, which would make it too hard to construct a factory within the region. The in-country factory would have to be designed, planned and constructed before a disaster happens.

Another fair point brought up during the presentation was about the level of customization that each community center would have, and if there is a way to modify the buildings. The shipping boxes used as the walls of the community center allows for some customization, offering a place for the local people to fill them with vernacular material. However, the form and size of the building stays the same, which is an idea that could be challenged with further exploration.

Although the roof of the community center catches the water and diverts it to large barrels for retention, it was suggested that the water system and other systems of sustainability should also be further researched.

The idea of using shipping boxes as part of the building was discovered later in the thesis process. This system can further be explored in regards to the size, assembly, and function of these boxes.

Finally, following the public presentation, a method of communicating the instructions for building was explored. Since this system of recovery is intended for

many different countries, it is imperative that the instructions transcend any language barrier. IKEA employs a set of directions without words allowing anyone to understand them. This concept of wordless instructions was investigated as a method for communicating the building instructions for the community center.

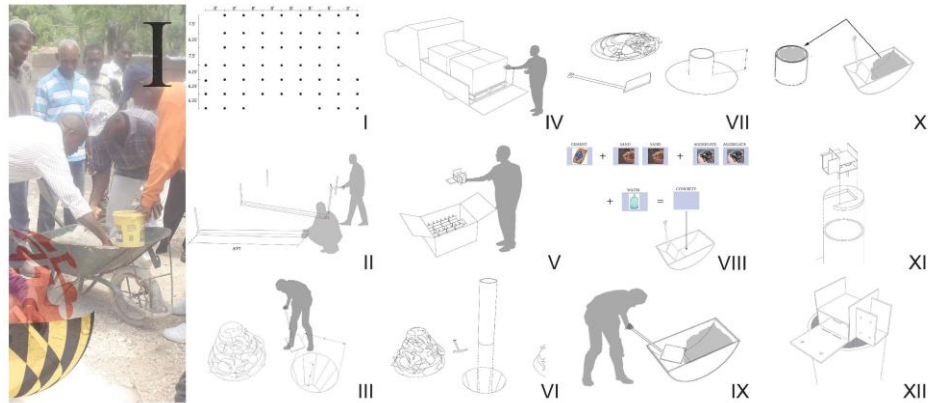


Figure 92 Wordless instructions shown in the form of a fold out pamphlet.

Moving forward with the ideas explored in this thesis, there are opportunities with competitions responding to natural disasters, and organizations such as Architecture for Humanity, Neighborhood Design Center, and the Rose Fellowship. This thesis responds to real life tragedies that unfortunately will always need responding to. Exploring these ideas of disaster relief transcends a school project, and will become a lifelong profession.

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