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Rapid Response Low Cost Housing System – Haiti Case

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Abstract

The catastrophic earthquake event in Haiti with its devastating consequences inspired exploration of rapid response low cost housing solution, with an emphasis on the dependence of local resources.

The objective of the paper is to present a concept idea of a housing solution using simple cost-efficient materials. The goal is to design a readymade structure either temporary or permanent that can suffice the basic necessities of living for any period time. The offered concept is intended to be used for a few weeks, or months, or possibly stand for years. The system is based on local recycling materials, such as packaging, cans, bottles, crates, rice sacks and others were explored.

Agricultural products such as bamboo, sugarcane and wood are present in only limited quantities; however hay is a typical traditional material for roofing in Haiti. Sand is available in unlimited quantities from the mountains, rivers and from the endless debris and rubble from the ruins.

The proposed solution is based on a viable and realistic concept driven by the devastating catastrophe. Haiti is a poor country and any complex, high-cost designs are not feasible. Realistic pragmatism with minimal prerequisites is offered. The warm climate of the Caribbean makes it possible to sleep outdoors even in the winter time; however, the offered solution provides a shelter from the forces of nature such as seismic activity and strong storms during the hurricane season.

1 Introduction

It has been a year now since catastrophe struck Haiti, devastating the lives of millions of people and leaving many Haitians without a place to call home. Today in Haiti, many rely on makeshift tent communities, these so-called “shanty-towns”, for living and these types of dwellings are not providing the necessary shelter these people need and deserve. Construction standards in Haiti are severely low and improperly planned. Buildings are poorly made and not well maintained. This is why so many homes were destroyed. The country still suffers from shortages of fuel and potable water, although significant improvements have been made since last January.

Haiti is a small island nation in the Caribbean with a population of roughly 9 million inhabitants. The largest population lives in and around the capital city of Port-au-Prince, which was only fifteen miles away from the earthquake’s epicenter. The region is mostly rugged with small coastal plains and river valleys. The climate is warm/semi-arid with high humidity in coastal areas. Geographic considerations must be taken into account when analyzing the proposed solution’s feasibility and strength to withstand the climatic conditions of Haiti. Cultural considerations must be noted as well. The vast majority of the population is of African descent and the indigenous languages spoken are French and Creole. Healthcare and the economy are weak in Haiti. It is the poorest country in the Western Hemisphere and approximately two-thirds of Haitians depend on farming, which remain vulnerable to damage from frequent natural disasters.

The concept is not to be the ultimate fix to all of Haiti's problems, but is to provide the Haitians with the basic essentials they need and ease the greater problem at hand, which is reliable housing. Through the use of cost-efficient materials, while taking into account lightweight structural design and the limitations of local materials, this proposed solution gives the Haitians a second opportunity to rebuild their lives and it all starts with rebuilding the home.

2 Preliminary Design Ideas

It is necessary to consider a variety of design methods and proposals in order to determine the optimal solution for this problem. Every possibility was examined and took into account issues of materiality, structural feasibility and relative ease of construction. The goal is to conceptualize a solution that will focus on the integration of local materials and efficient structural design. It was also important to note the various cultural and social factors that can contribute to the design and arrangement of dwellings. Investigation began with studying the essential two categories of structures, compressive and tensile.

2.1 Compressive Structures

The focus is on design and structural arrangement of building typologies at first. Concerns for materiality were not heavily considered during this phase of the investigation process, although, it was important to have a fundamental understanding of what materials were available in Haiti.

The focus was to provide a roof, a place of protection, for the Haitians. We first looked at basic hut-like structures, with the most rudimentary elements, walls and a roof. Figures1 and 2 illustrate this idea of the hut, constructed with a variety of materials. The primary structural elements are bamboo shafts. They are bundled together in the center to create a column for the support of the roof. The roof would be constructed in a radial manner out of bamboo and rice bag sacks and the walls would be built from hay bales. The central column shaft can also be used to collect rain water and the structure can house up to one immediate family.

Figures 3 and 4 take the same notion of the hut but instead, embed it into the ground. The earth would be the walls of the hut and the roofing would be constructed from bamboo and hay. A concrete ground cover layer would be added for protective purposes. The triangulated roof is a stable structural system since the natural shape of the triangle by definition is the most stable.

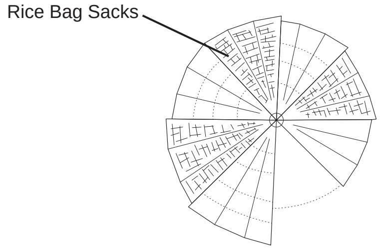

Fig. 1: Hut-like structure roof plan

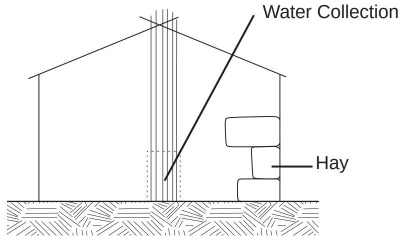

Fig. 2: Hut-like structure section

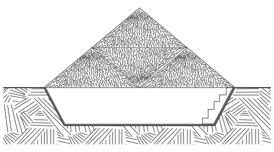

Fig. 3: Hut-like structure section

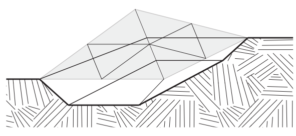

Fig. 4: Hut-like structure axonometric

Also, the roof is directly supported by the ground, possibly routed to the ground with concrete supports. The disadvantage with this arrangement as a whole is that rainwater would collect into the dwellings. Thus, additional materials and layers are needed.

Therefore we moved into the investigation of typical brick style construction. Discussion emerged concerning what types of materials we could utilize most efficiently and it came clear that utilizing hay would be the best choice both for its abundance as well as its cost. Hay can be bundled into square bales and function as bricks, becoming building blocks. The concept of a modular system works best because the inhabitants can build it themselves given a set of instructions. Figures 5, 6 and 7 illustrate this idea. However, it is difficult to attach a roof to a hay bale. For the majority of hay structures that have been built, there has been some type of wooden truss framework that has been established for the roof that we thought is not available for our case.

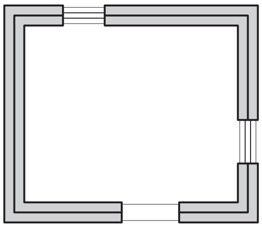

Fig. 5: Hay bale house plan

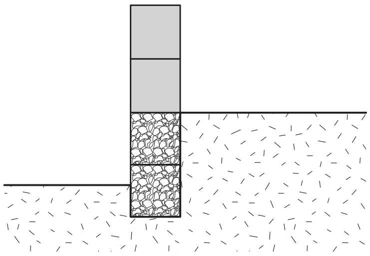

Fig. 6: Foundation section constructed of rubble

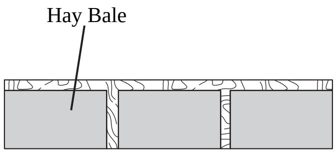

Fig. 7: Bale construction detail

From there we moved onto domed and arched hay structures, eliminating the use of a separate roof system. Utilizing the same principle of hay bale structures, they could be used not only as the walls but as the roofs of the buildings as well. This would eliminate the need to have a wooden framework for this project. Figure 8 illustrates this concept. Construction of this may cause difficulty although the dome could be constructed in in-plane circles that would gradually get smaller as it approaches the top. This is demonstrated in figure 9.

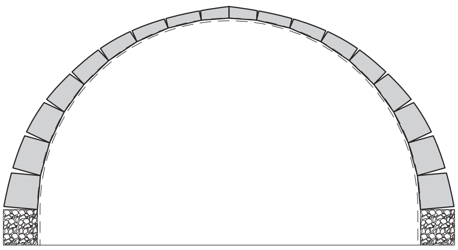

Fig. 8: Hay bale dome. With this approach, the walls and roof are the same material throughout.

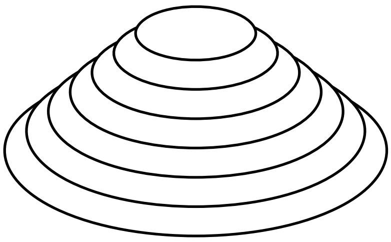

Fig. 9: A dome constructed in in-plane circles that would gradually get smaller.

There would also need to be some type of foundation and compression rings so that the hay would not only not be touching the ground where it could get damaged, but also to provide the support needed to hold a dome together. To do this, at the bottom of the structure, we planned on using a simple solution by filling the coffee sacks that are so abundant in this region with debris and rubble. This would provide heavy-weight building blocks than can raise our structure and support the outward loads exerted by the dome. We then examined more complex dome typologies, such as pendentive domes. The idea behind the pendentive dome is that it would eliminate the need for a compression ring around the bottom circumference of the structure. It also would allow for more headroom. This is described in figures 10 and 11. Building this dome or the webbing that supplies the roofing of the pendentive posed to be a challenge on its own. Constructing this might be a bit difficult due to the lack of scaffolding available as well.

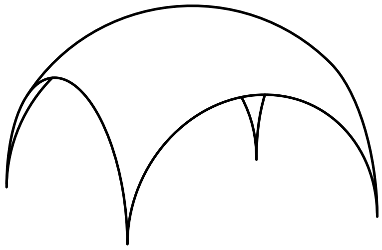

Fig. 10: Pendentive dome. Eliminating the need for a compression ring.

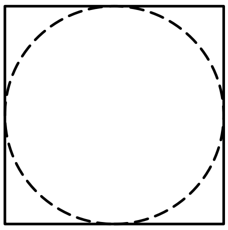

Fig. 11: Pendentive dome plan. Usable space and headroom.

2.2 Tensile Structures

Concerning tensile structures, we looked into the possibilities with cables and tents. Tensile structures can afford opportunities that compressive structures cannot, such as using lighter materials and spanning greater distances.

One of the first ideas considered was developing a system using plastic bottles, sand and ropes. The idea is to create a hut-like dwelling with a central column shaft, made of vertically stacked plastic bottles filled with sand. A series of ropes, routed to the ground, would be strung upwards to the roof through the bottle. The ropes would be tense and strung along the roof to create support for the roof all the way to the walls. The walls would be constructed of horizontally stacked plastic bottles filled with sand and the ropes would snake through the bottles to provide support for the walls. The ropes would then reach the ground, where they would be secured and tensed. A simple roofing material such as burlap or hay can be placed on top. Consequently, the structure is secured entirely out of ropes in tension. This idea is illustrated in figures 12 and 13. The advantages of this solution are that the heavy walls can provide thermal insulation; the structure has a degree of flexibility in case another earthquake strikes and it uses light tension members. It may be the case that there may not be a large enough plastic bottle supply; the construction process is slow and in case of fire, plastic bottles can release fumes that may be carcinogenic.

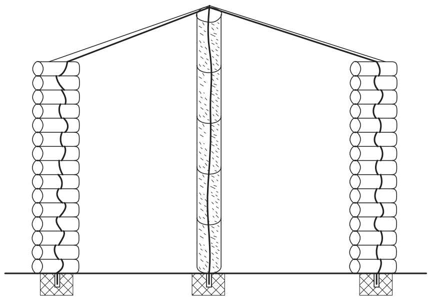

Fig. 12: Bottle sand structure section. Ropes used in tension to hold elements together

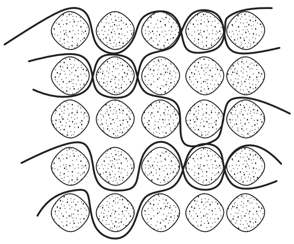

Fig. 13: Ropes snaking through the plastic bottles in section.

Another solution we re-examined is the hay bale structures and finding another solution for the roofing problem. The primary concern was the fact that hay bale structures would need a different structural system for the roof. Thus, we proposed a tent system for the roof; however, each dwelling would not have its own tent, but rather a whole tent would span various dwellings creating a community of structures. There is one large shared roof for all houses. This concept is demonstrated in figures 14, 15 and 16. The tent would ideally be made of burlap or some other similar material and would be anchored into a mound to provide tension. The mound would be constructed of earth and rubble from the wreckage of the earthquake.

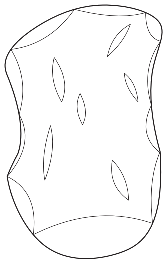

Fig. 14: Tent Community
Tent-like community housing.

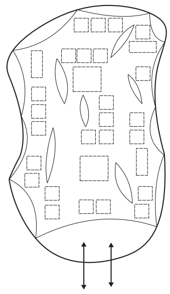

Fig. 15: Tent Community
One shared roof for all the houses.

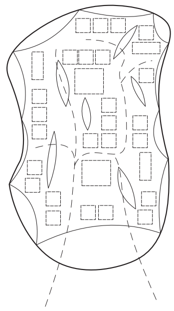

Fig. 16: Tent Community
Small openings provide light.

Figure 17 shows this idea. There would also be reinforced punctures in the fabric roof to bring sunlight into the tent community, as shown in figure 18. This is quite unique from the other proposals because takes into account the social considerations of living in shared spaces.

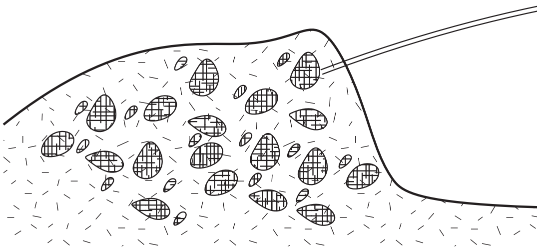

Fig. 17: The tent is anchored into a mound of rammed earth and debris for supports.

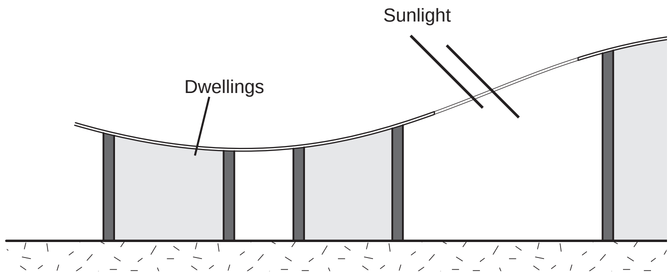

Fig. 18: Houses vary in size and snlight penetrates openings.

All of these concepts provide a great variety of solutions for basic dwellings. Individually each solution has pros and cons yet the last one may be the most suitable solution as a rapid response.

3 Material Explorations

Available materials are relatively scarce in Haiti, due to the fact of limited resources and limitations of importing. Therefore, we relied on what is on hand in Haiti. This is optimal for the people of Haiti because they will have direct access to the resources they need, further facilitating the construction process on their own. The idea is to limit the construction materials to only local resources.

Several materials that were considered included plastic bottles, sand, hay, debris, burlap, bagasse and sugarcane. The advantages and disadvantages of each material were weighed to determine which one would be best to serve as the optimal building material. The benefits of using plastic bottles include stackablity; they can be filled with sand or debris to weigh them down; they can be molds for sand casting and they could also be used for water collection. A disadvantage of using plastic bottles is obtaining a large enough number to make it a feasible construction material. The primary advantage of using sand is its abundance and availability; however, it must be used in combination with other materials, such as the plastic bottles, because sand alone is fairly useless. It is important to note that when considering the different material choices, we must also think about the climate. The material chosen must be able to withstand the climatic conditions of Haiti and protect the inhabitants of the dwelling from various weather conditions. Hay is good option because of its ability to be rolled and stacked to make walls and roofs. The problem with hay is that it doesn't grow in abundance in Haiti. Debris was considered as a feasible building resource because of the rumble and destruction leftover after the earthquake. It can be used as a filling material much like sand or it could serve better for foundation aggregate for dwellings. An unusual material that was examined was bagasse. It is the fibrous matter that remains after sugarcane stalks are crushed to extract their juice. It is primarily used for the manufacture of pulp, paper products and building materials. It is a very fibrous material with a high moisture content. The benefit of using bagasse is that sugarcane is widely abundant in Haiti; however, it is a highly flammable material often used as a bio-fuel.

After examining a variety of building material possibilities, we narrowed down to burlap and sugarcane as the most practical and sustainable building materials. Burlap is used throughout Haiti for coffee and rice sacks. Coffee and rice are two of Haiti's most important exports, so therefore there must be a large quantity of burlap sacks, used and new. Burlap is excellent for spanning distances and it can be used to create ropes and act as a tensile element. Sugarcane proved to be a viable building resource because of its vast advantages and abundance. The material grows locally in Haiti in large quantities. It behaves as a structural element similar to bamboo, which is used widely in various Asian countries for scaffolding. Elements can be bundled together to create columns or tied to one another to produce an assortment of structural typologies. It can be used for quick construction uses. Also, different material properties exist depending whether or not the sugarcane is dried or wet. This affects its compressive and tensile characteristics and its lifespan as well. Due to the numerous possibilities that sugarcane can provide, we tested its compressive and tensile qualities.

3.1 Compression Tests

The first tests conducted were compression tests using a compressive tester in the lab, to determine compressive strength, yield strength and modulus. Given that the sugarcane holds different properties when it is either wet or dry, several trials were conducted in both states of the sugarcane. Another characteristic of the sugarcane that was taken into account when testing was, whether or not the specimen had ridges, as shown in figures 19 and 20. The ridges of the sugarcane give it additional strength and affect the results.

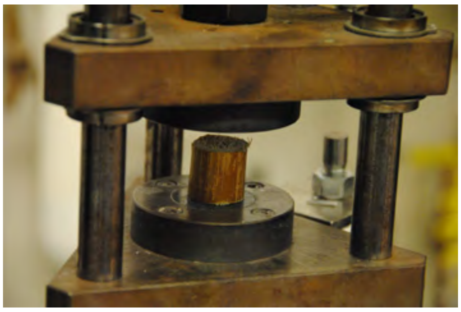

Figure 19: Smooth sugarcane specimen about to undergo compression test

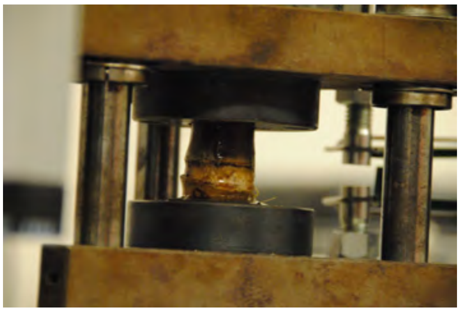

Figure 20: A sugarcane specimen with ridges undergoing compression test

In trail 1 the specimen was wet and contained ridges. It was two inches tall and half of an inch in diameter. The specimen was compressed at a rate of one millimeter per minute until it failed. Figure 21 shows the graph and its compressive strength is 10.7 MPa. In trail 2 the specimen was wet and smooth; there were not ridges. It was one and a half inches tall and half of an inch in diameter. The specimen was compressed at a rate of one millimeter per minute until it failed. Figure 22 shows the graph its compressive strength is 6.6 MPa.

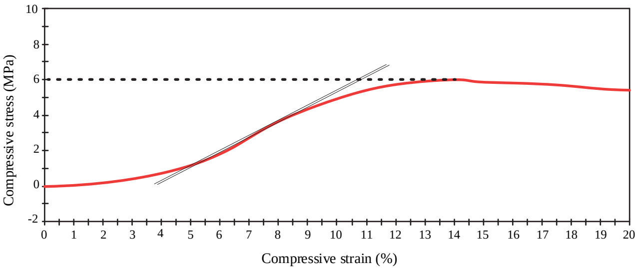

Figure 21: Wet with ridges specimen

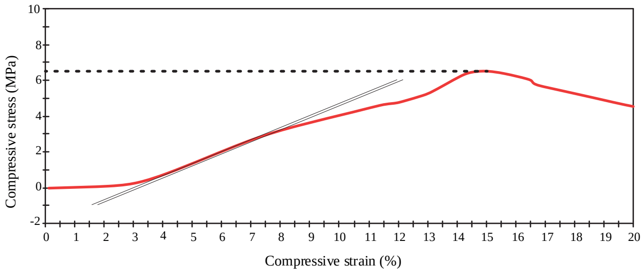

Figure 22: Wet and smooth specimen

In trail 3 the specimen was dry and contained ridges. It was left to dry in open air for several days prior to testing. It was one and a half inches tall and half of an inch in diameter. The specimen was compressed at a rate of one millimeter per minute until it failed. Figure 23 shows the graph its compressive strength is 6 MPa. In trail 4 the specimen was dry and smooth. It was two inches tall and half of an inch in diameter. The specimen was compressed at a rate of one millimeter per minute until it failed. Figure 24 shows the graph and its compressive strength is 9.5 MPa.

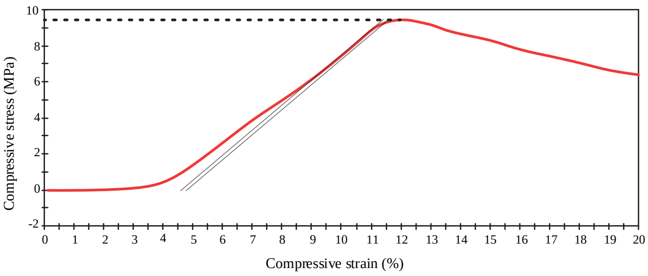

Figure 23: Dry with ridges specimen

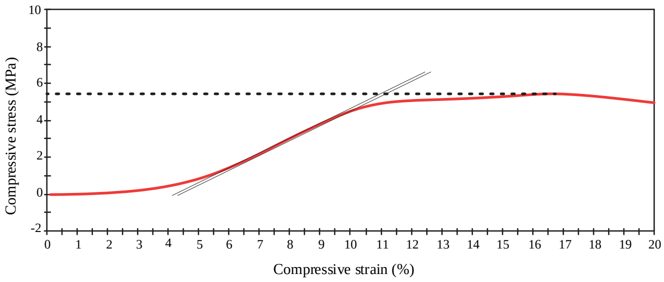

Figure 24: Dry and smooth specimen

The results indicate, it is good to use the sugarcane once it is cut and wet. As it dries, its lifespan decreases; therefore, it would be ideal to construct in a wet state and allow the structure to dry out overtime. The estimated lifespan of sugarcane before it becomes unstable is two years. The numbers are fairly small for the compressive strength, so it would be best to not place the members under a significant amount of stress. Sugarcane is brittle and cannot withstand large loads. No conclusive results were determined on whether or not ridged shafts were more beneficial that smooth ones. For our purposes, either can service our needs.

3.2 Tensile Tests

The second set of tests conducted were tensile tests using a tensile tester in the lab, to determine tensile capacities. Load was applied to two specimens, one wet and the other dry. The specimen was stretched until it reached maximum tensile stress, as shown in 25 and 26.

Figure 25: Side view of sugarcane specimen undergoing tension test

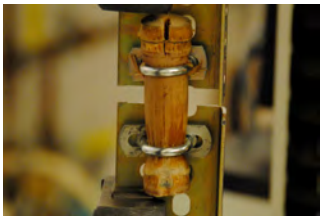

Figure 26: Front view of sugarcane specimen undergoing tension test

In trial 1 the specimen was dry. It was two and half inches tall and half an inch in diameter and stretched at a rate of one millimeter per minute. The maximum tensile strength achieved was 3 MPa. Figure 27 shows the graph. In trial 2 the specimen was wet. It was 3 inches tall and half an inch in diameter and stretched at a rate of one millimeter per minute. The maximum tensile strength achieved was 5 MPa. Figure 28 shows the graph.

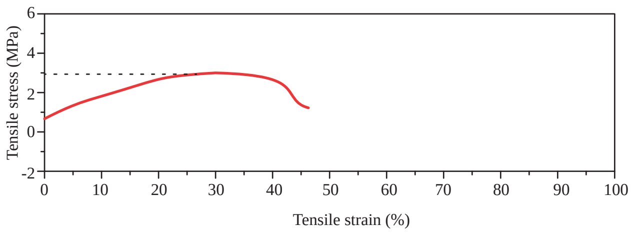

Figure 27: Wet with ridges specimen

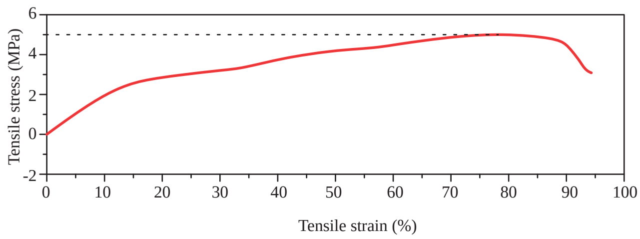

Figure 28: Wet and smooth specimen

The results indicate that wet sugarcane exceeds dry sugarcane in compressive strength. The tensile stress of the sugarcane was roughly 50% the compressive capacity, while the tensile strain was much larger because of grip slippage. Thus, the tensile strength was not fully achieved.

4 Connection Types

Various types of connections between the sugar cane pieces were explored. A possible method would be to use burlap ties because the same material is being used to cover the structures. The fabric can be split into many pieces and proves to be strong enough as a material to tie with. It can be used to tie bundles of sugarcanes to create column shafts or it can be used to tie two shafts from end to end, as shown in figure 29. A grid system for walls or roofs can be fashioned out of the shafts and tied together with the burlap ties as well. This concept is illustrated in figure 30.

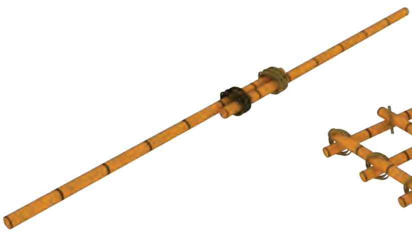

Figure 29: Two sugarcanes tied with burlap

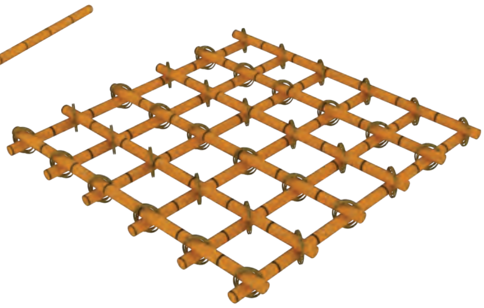

Figure 30: Sugarcane grid system

Figure 31: CMU and sugarcane combination

We had also considered using the sugarcane in combination with other materials such as concrete. It is possible to use CMU construction blocks, concrete and sugarcane to create foundations for structures. As illustrated in figure 31, sugarcane is placed in the openings of the CMU block and then filled with concrete. This secures the sugarcane to the CMU, which could be buried into the ground and serve as foundation.

Considerations were also made about using the sugarcane to support itself without ties. Depending on the arrangement of the sugarcane shafts, it is plausible to create a reciprocate structure where members of the system is supporting itself mutually. It is the idea of using one sugarcane cane to hold up or lock into place two others. Figures 32, 33, 34 and 35 illustrate proposals for these types of reciprocate structures.

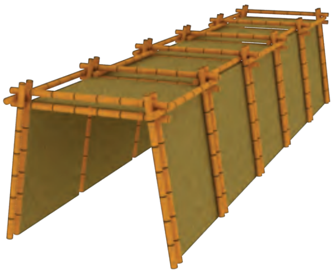

Figure 32: Square hut reciprocate system

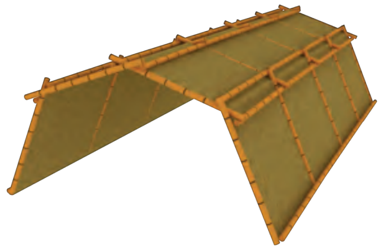

Figure 33: Tent hut reciprocate system

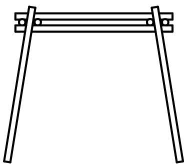

Figure 34: Square hut section

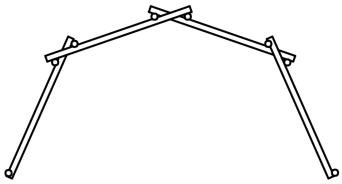

Figure 35: Tent hut section

5 Programmatic Typologies

In order to properly size and partition each dwelling, it is necessary to determine the exact requirements of the Haitian needs. Typically, Haitians live with their extended families in communal style living. This is the social norm of their culture. Each household can have up to as many as 18 people living in it. Our idea is to create a living situation where groups of extended families live together to create micro-communities of no more than 15 families. Therefore, the rough size of one community would be as large as 300 people.

With these micro communities, you get the benefit of communal living without the burden of overcrowding. Certain facilities and services can be shared, such as bathrooms and kitchens. Each individual would need at minimum one hundred square feet. Thus, if 18 people live in one household, the dwelling must be at least 1,800 square feet. Program for the dwellings would be divided between public, private and circulation spaces. The public space would consist of a common room, roughly 700 square feet in size. The private space would include various sleeping quarters, shared amongst family members, with a total size of about 1,000 square feet. The remainder of the square footage would be dedicated to circulation spaces within the dwelling.

Once the size was determined, the next step was to consider configurations. There are four basic program typologies we developed based on the given requirements and size; the circular, square, bar and L plans. Each type affords their own benefits. The radial plan is advantageous because all the private spaces have equal access to the common room. The benefit of the square plan is that it is much easier to construct at right angles then in a circular fashion, like the radial plan. The rectangular or bar plan is good because there is a clear separation between the public and private areas. The L plan takes the bar plan and multiplies it creating wings that generate off of the common room. These configurations are illustrated in figure 36.

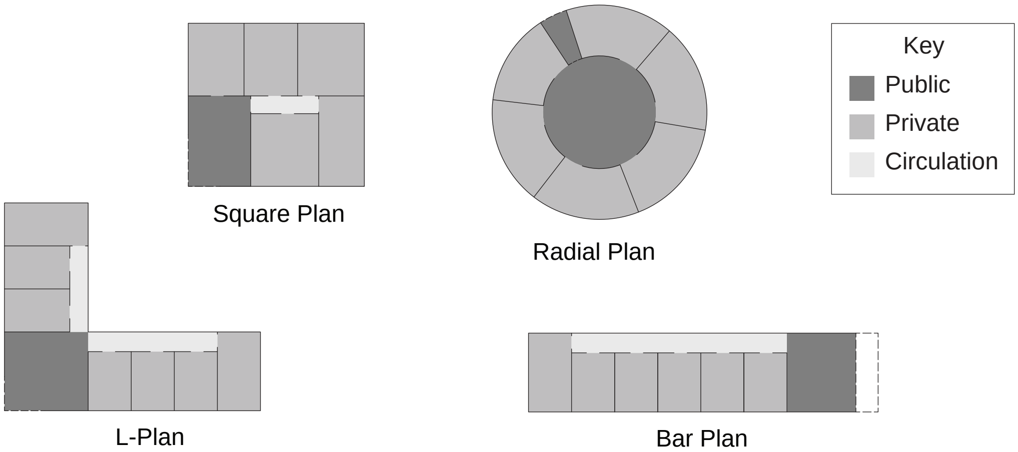

Fig. 32: Program Typologies

6 Summary

This investigation explores a practical and reasonable housing solution for the problems in Haiti. It is determined that sugarcane is suitable for structuring temporary dwellings given that both their compressive and tensile capacities could be comparable. A possible solution is a combination of the sugarcane with burlap and concrete to produce a variety of housing typologies located in concentrated social communities.

Through this investigation we had examined a variety of materials and methods to produce a rapid response housing solution that may work for the Haiti case. However, not only does this solution apply to Haiti, it can apply to any rapid response housing situation. Efficient use of limited materials and structural feasibility were the driving forces generating a solution that may work best for the Haiti case.

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