Spring 2010

# Make It Complete With Papercrete

Garrett McElroy, Charis Thompson, Kayla Williams

HelpHaiti

Engineering 215 Intro to Design

# Table of Contents

# TABLE OF FIGURES

# 1. PROBLEM FORMULATION

## 1.1. INTRODUCTION

The purpose of Phase 1 of the design process is to develop an idea for the project that allows us as a team to define our project as a whole. Along with the objective statement, a Black Box Model was constructed in order to describe how shelters currently are and how they will be after our design implementation.

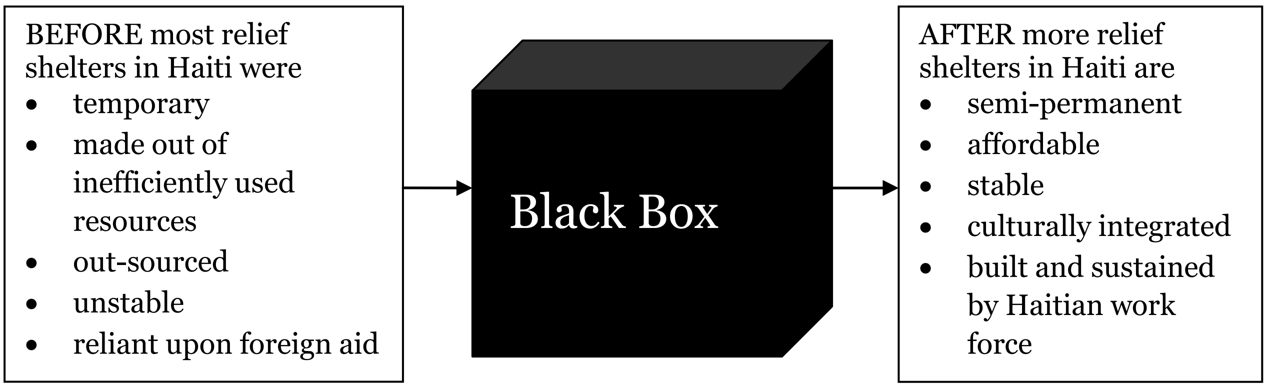



**Figure 1-1: Black Box Diagram**
**This model displays the changes that will take place among shelters in Haiti after our design is implemented.**

## 1.2. OBJECTIVE

The objective of this project is to design and build a rigid, cost effective inner wall of the World Shelter's JAS system. The project intentions are to create a durable, rigid, long lasting, and cost effective interior wall.

# PROBLEM ANALYSIS AND LITERATURE REVIEW

## 2.1. INTRODUCTION

The problem analysis and literature review is the first step to evaluating and investigating creative resolutions to the assigned problem. This section is a collection of the researched material that will be used as the basis for all possible solutions. The literature review will discuss the requirements assigned by the client as well as a thorough review of the pertinent uses of the following viable resources: dirt, rubble, bamboo, plastic, cement, and wire mesh.

## 2.2. Problem Analysis

### 2.2.1. Specifications

- Rigid
  - Inner wall system must be stiff with little flex.
- Durable
  - Structure must be sturdy and able to withstand expected living conditions.
- Replaceable
  - A damaged or old wall must be able to be removed and then replaced with a new wall of the same design.
- Long lasting
  - As an extension of durability, the wall system must have a reasonable life-expectancy (five years or longer) assumed expected living conditions are maintained
- Lightweight
  - The wall design must have a weight around that of a customary wall system.

### 2.2.2. Considerations

- Element Resistance
- Cost
- Renewable
- Insulative
- Waste

### 2.2.3. Constraints

| Criteria | Constraints |
|---|---|
| Cost | Lowest cost possible |
| Materials | Need to be local or already shipped in |
| Labor | Must be supplied by Haitian workers |
| Skill | Must be able to be built by unskilled workers |

## 2.3.

## 2.4. Literature Review

### 2.4.1. Introduction

The purpose of the literature review is to collect and analyze information which may lead to possible solutions to the project objective. Topics being discussed in this literature review will include the applications and benefits of constructing with various materials which include rubble, bamboo, Papercrete, plastic, and the method wattle and daub.

## 2.4.2. Client Criteria

The client representative administering the progress on this project is World Shelters' affiliate Kurt Therkelsen. After meeting with him for an initial round of questioning, consequential requirements were noted and then considered during later research.

- **Zero Cost Goal:** Spending for this project will be next to nothing due to prioritization of all World Shelters projects. Therefore, it is necessary to utilize free or negligible cost materials, transportation and construction inclusive.
- **Long Lasting:** The project's findings will double as a resource for other World Shelters projects. This increases the requested life span of the system from a couple years to as long as is feasible.
- **Rigid and Durable:** In order to achieve the desired longevity, the system must be durable. The wall system requires rigidity so it has the functionality of a normal inner wall structure.
- **Replaceable:** If the wall needs to be replaced, there needs to be a readily available process the small community can go through to get a new wall. This needs to be possible regardless of time passed after initial installation.
- **Renewable Materials:** For the system to be replaceable, materials must be around and plentiful years after implementation. Additionally, the method needs to support mass production of shelters. This means the materials need to be local and from a renewable source.
- **Local Labor:** Utilization of the local work force drives self-sufficiency as well as reducing foreign dependency and possibly creating more jobs.
- **Element Resistance:** The wall must withstand degradation from surrounding elements as well as possible hazards like fires and hurricanes.
- **Insulative:** More thermal insulation increases value of the system.
- **Lightweight:** More viable and reasonable wall structures maintain a lower mass which assimilates customary inner wall systems. This also ensures increased safety.
- **Environmentally Friendly:** Production and installation must be efficient and minimize waste.

## 2.4.3. *Wattle & Daub*

Wattle and daub is a building method used to make either interior or exterior walls of a building (Pritchet, 2001). It has been used in construction for many centuries, mainly in Europe and is regaining popularity in many developed countries as a sustainable building technique (Graham, 2003). Wattle and Daub is made by weaving strips of wood into a lattice and then daubing it with a mixture of clay, sand soil and animal dung. It is a cost effective and environmentally safe way of constructing buildings and has a low construction and maintenance cost

Wattle, the first step of wattle and daub, is made by weaving strips of branches into a firm secure lattice held in place by a wooden frame. The second part, daub, is created by combining sand and crushed chalk or rubble (Pritchett, 2001). Next, a mixture of clay, limestone or chalk dust is added to hold the contents together. This mixture is then applied to the wattle to hold it firmly in place as can be seen in Figure 2.3-1. Reinforcements are then added, such as straw or hay, in order to increase sturdiness and flexibility. Daub can either be mixed by hand or by treading: mixing the daub by foot as sometimes done using cattle. The daub is then applied to the wattle and left to dry. The end product of wattle and daub is often white washed to prevent rain damage and adds to the aesthetic appeal of the structure (Sunshine, 2006).

The following discusses the benefits and drawbacks of using wattle and daub for construction.

## Advantages

Wattle and Daub is useful in construction as:

- The materials used for wattle and daub are inexpensive (Pritchett, 2009).
- Little skill is required for construction compared to those needed for many other building methods (Sunshine, 2006).
- Wattle and Daub has a long life span (Sunshine, 2006).
- The materials used to construct wattle and daub homes are easily accessed (Graham, 2003).

## Disadvantages

Wattle and daub may not be practical for construction in modern day homes since:

- Wattle and daub may not be aesthetically appealing.
- The clay in the daub often cracks, decreasing the lifespan (Pritchett, 2009).
- Wattle and daub is not element resistant (Pritchett, 2009).
- The daub used for construction is not a good insulator (Sunshine, 2006).

The remains of a wattle and daub hut after the flood washed away its clay walls

**Figure 2.3-1: Here is a wattle and daub hut after a flood (wsw,2000).**

### 2.4.4. PAPERCRETE

Papercrete is a recently developed construction material which consists of re-pulped paper fiber with Portland cement or clay. Portland cement is the most common type of cement in use around the world because it is the main ingredient found in concrete, mortar, stucco and most non-specialty grout (PCA, 2010). The paper to be used can come from a variety of sources: newspaper, junk mail, magazines, and books (Hart). Sorting through the local dump or waste bins is a useful way of collecting the paper. Depending on the type of mixer used to pulp the mix, the paper may be soaked in water beforehand. Papercrete gets its name from the fact that most formulas use a mixture of water and cement with cellulose fiber (Hart). The fiber is usually acquired from recycled newspaper, and phone books due to availability and low cost. Figure 2.3-3 (Hart). The mixture has the appearance and texture of oatmeal and is normally prepared by pouring into forms and drying in the sun, much like the process for making adobe. Dried Papercrete has low strength, but this characteristic is only due to the large air content in the bricks which allow them to compress rather than crumble and brake. Concrete and wood are not known for their insulating qualities; however, Papercrete provides insulation. Unlike concrete or adobe, Papercrete blocks are lightweight, less than a third of the weight of a comparably-sized adobe brick. Papercrete is mold resistant and has the ability to be a sound-proofing material (Hart).

Structural tests have been completed on several Papercrete formulas and results have shown that the compressive strength of Papercrete is 140-160 pounds per square inch. The stiffness of Papercrete is many times less than that of concrete. Therefore, it will compress under load, but has actually been proven sufficient for the support of roof loads in some low-height buildings. Papercrete has also been tested for its tensile strength. A Papercrete block is the equivalent to one hundred pages of paper - almost like a catalog (LIP, 2007).

This section categorizes the benefits and drawbacks of building with Papercrete.

### Advantages

- Papercrete has insulation properties.
- Because less energy is required to heat and cool, savings accumulate over time.
- The use of paper recycles materials that may have ended up in a landfill
- Papercrete walls will not rot and are impenetrable to insects (Hart).

### Disadvantages

- Papercrete is not as structurally sound as solid concrete which is a denser material.
- It takes three days for Papercrete blocks to dry and cure, so construction may be extensive and conscious of whether conditions.

**Figure 2.3-2:** **Papercrete is used to build a structure (Timhp, 2005)**

**Figure 2.3-3:** **Papercrete blocks are drying in the mold (Sanders, 2009).**

## 2.4.5. EARTHBAGS

Earthbags, which are commonly referred to as dirtbags or sandbags, are an inexpensive and simple construction method for building a wall or even the frame of a structure (NRCS, 2000). The materials required are earth and bags; each bag is filled with dirt and stacked on top of each other to form a thick wall.

The material which the bags are made out of should be non-biodegradable; depending on the material used, degradation of the bags over time can be a concern. The bags that are most commonly used are untreated burlap sacks but they deteriorate quickly (Hart). Polypropylene bags will not deteriorate for a long time and only need minimal care, but are not very safe for the environment because they will not biodegrade (US Army Corps of Engineers). The bags should be about 14-18" wide and 30-36" deep for most successful stacking (US Army Corps of Engineers).

The dirt used to fill the bags can vary. One method is mixing the dirt with concrete so the bag solidifies after time; this makes permanent the shape of each bag, thereby creating interlocking puzzle pieces, which in effect further secures the structure (NRCS, 2000). If cement is not available, heavy or sandy soil would best for use in construction. The coarser the earth the more permeable the bag so it is best to avoid gravelly earth (US Army Corps of Engineers). However, dirt and other finer fill are susceptible to mold (Hart).Construction of sandbags does not require much skill or previous knowledge. They require two people to fill and usually one person for transportation of the bag. The procedure, which is shown in Figure 2.3-4, requires filling the bag, folding the flap over, laying the bag down so the flap lays under the weight of the bag, and stacking in a stair step pattern.

For added stability, cut barbed wire or wire mesh (as is available) to the width of the wall and in strips the length of the wall, and lay between each two dirtbag layers. This reduces the likelihood of the bags slipping.

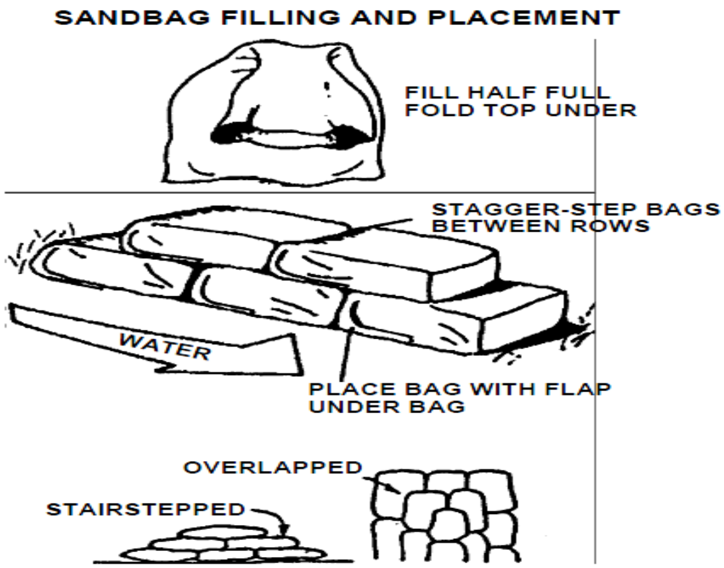



**Figure 2.3-4: Diagram of Sandbag Construction (NRCS, 2000).**

This section categorizes the advantages and disadvantages of using earthbags for construction.

## Advantages

This method is beneficial in the sense that an earthbag wall:

- Utilizes renewable resources. Dirt is plentiful, polypropylene plastic sheeting and wire mesh sent as relief aid can be sewn into bags and used to secure the piles, respectively.
- Is low cost when materials are required resourcefully, such as using relief aid plastic sheeting. Costs include transportation of materials, labor required to build, and tools needed to sew the bags (thread, needles, etc.)
- Is a long-term option. Provided that the bags are made out of protected (UV radiation resistant) polypropylene plastic or not placed in contact with sunlight, the earthbags will last many years.
- Is rigid and can bear a large horizontal or vertical load.
- Can withstand severe weather such as flooding, earthquakes, and even stops bullets (Hart).
- Is well suited for inside use as opposed to the shelter's framework because direct sunlight will degrade the bags (Hart).
- Can utilize local labor which will be continually available if a wall needs fixing or replacing.
- Provides insulation. Depending on the material used to fill the bags, this method can be an efficient insulator; volcanic rock is one fill option that has high insulation properties (Hart).
- Produces minimal waste; possible byproducts are excess wire, thread, or polypropylene.

### Disadvantages

Earthbag construction is unfavorable due to the fact that structures are:

- Not water resistant. In the case of hurricanes and floods, water will seep through the wall. Repeated wetting will shorten the life of the earthbags (County of San Bernardino, 2004).
- Not lightweight. Each bag (filled with adobe) will be approximately 30 lbs. (US Army Corps of Engineers).
- Quick to degrade. If natural sunlight reaches unprotected polypropylene bags, through a window for instance, they will degrade more rapidly than if they were protected and the lifetime of the bags will decrease.
- Thick and will decrease the total living area in the JAS System.

## 2.4.6. Bamboo

Bamboo is of recognizable economic and cultural importance in East Asia, the South Pacific and to some extent in South America, where it is typically used as a building material (McClure, 1981). There are over 1600 species of bamboo, of which many can be found in the Caribbean. Bamboo is a woody, sturdy tropical plant and is capable of growing up to twenty four inches in one day. Bamboo is strong, versatile, and when the right technology is applied, can be very useful for construction as it is cost effective and safe for the environment. An example of a house constructed out of bamboo can be seen in Figure 2.3-5 (Davidson, 2008). Using bamboo for construction would be highly beneficial for many developing countries. Construction with bamboo is typically done in two different ways. The first involves the bamboo being set up as poles and used as support for the infrastructure of the building. Bamboo is excellent for this as it is rigid and the stalks are very thick. The second is the use of split bamboo, where the bamboo is split in half and typically used for flooring, roofing and support for the infrastructure of the building (Adams, 1998). Bamboo can be made to form different shapes by training it to grow into the structural shapes desired. This method is more cost-effective than the procedures necessary to shape wood (Strangler, 2009).

This section analyses the benefits and drawbacks of using bamboo for construction.

### Advantages

Bamboo is an ideal resource for construction since:

- Bamboo can be easily found in the Caribbean (Davidson, 2008).
- Bamboo has a low cost (Davidson, 2008).
- It is aesthetically appealing.
- Bamboo is durable and has a long lifespan (Einav, 2009).
- Bamboo is easy to build with (Adams, 1998).
- Construction with bamboo has little impact on the environment (Davidson, 2008).

### Disadvantages

However bamboo may not be a viable resource for building materials since:

- Bamboo is highly susceptible to fungi and bacteria if it is not treated (Pelton, 2004).
- Bamboo requires maintenance to ensure a long lifespan.

- Cost for bamboo is increasing as more and more people recognize its value (DeVries, 2002).

**Figure 2.3-5: This is a home made out of Bamboo in South East Asia (nowpublic.com, 2009).**

## 2.4.7. Rammed Earth

Building with compressed dirt has been used for centuries, and in some cases like the Great Wall of China which has a section built out of rammed earth, rammed earth has lasted just as long. By its very nature, earth is one of the best sustainable building materials as it is historically the longest used material by man. It is a naturally available product; has a large thermal mass; and is a natural barrier to cold winds, forces of nature, insects, and rodents. Rammed earth housing has been shown to resolve problems with homelessness caused by otherwise high building costs, as well as minimize deforestation and toxic building materials associated with conventional construction methods. Utilizing rammed earth involves a process of compressing a damp mixture of earth with suitable proportions of sand, gravel and clay into an externally supported frame that molds the shape of a wall section. This creates a solid wall of earth (Bill & Stephen Betzen, 2006).

The mix is prepared by adding some cement, color if desired, and sprayed with a modest amount of water while being mixed. The addition of cement creates stabilized rammed earth (SRE). This means that the clay, which acts as a binder in the material, will not be able to reabsorb water and has therefore been stabilized. This creates a stronger and more durable wall, as shown in Figure 2.3-6. The material is mixed together until it is the consistency of cookie dough, which makes it optimal for compaction. There are a variety of ways to mix the rammed earth material. The most common way used today is through a Bobcat (small earthmover) or similar machine, but can be mixed by hand or with other devices such as a volumetric mixer (RE, 2010).

The following section includes the advantages and disadvantages which were arrived at from research on Rammed earth.

### Advantages

- The thermal mass of the walls provides insulation (RE, 2010)
- The walls contain no fungicides or pesticides that will off-gas (Hart)

- Walls can be a work of art using different; colors, material layers, shapes, details, or embedded objects (RE, 2010)
- Walls can bear load, handle multiple floors, and support heavy roofing systems.
- Rammed earth is long lasting; many hundred year old buildings built out of rammed earth are still in service (RE, 2010)
- Walls will not rot and are impenetrable to insects (Hart)
- Earth walls blend in with the natural environment.

### Disadvantages

- Rammed earth walls can be washed out and lose structural integrity if not protected from water (Bill & Stephen Betzen, 2006)

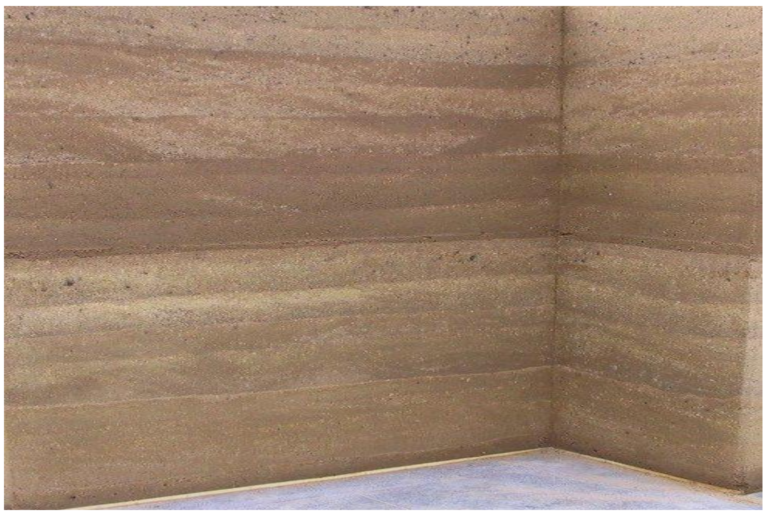


**Figure 2.3-6: Two walls made out of rammed earth (Design Build Live, 2010).**

## 2.4.8. Plastic

The plastic that will be utilized in the sustainable structures in Haiti will be the plastic sheeting sent in as relief aid (Kurt Therkelsen). Traditionally, the plastic sent to Haiti is used as shown in Figure 2.3-7. However, the plastic can be used to enhance other methods as well as serve as a method in its own right.

**Figure 2.3-7: Plastic sheeting is used by this Haitian family for shelter (Samaritan's Purse, 2010)**

On its own the plastic is very lightweight, but depending on the plastic, may lack rigidity. Finding out what type of plastic is available in Haiti is vital to assessing its realistic applications.

One practical use of plastic is recycled plastic lumber (RPL) as shown in Figure 2.3-8 (Cal Recycle, 2010). There are different types of RPL, all of which are similar to wood. One type, Commingled RPL is made out of primarily polyethylene, a plastic that is abundant in most areas. Because of this, sorting of the plastic is reduced and sometimes eliminated, making it the lowest cost of all types of RPL (Cal Recycle, 2010). The plastic is melted and remolded to form any desired shape. RPL is more flexible than wood which may affect rigidity and durability.

The advantages and disadvantages associated with this method of melting plastic are listed as follows:

**Figure 2.3-8: This person is producing RPL (British Recycled Products).**

## Advantages

Using this method to build an inner wall is advantageous because RPL:

- Is resistant to moisture and chemicals (Cal Recycle, 2010).
- Will not splinter or crack (Cal Recycle, 2010).
- Will not deteriorate. Sealants or preservatives are unnecessary because RPL does not naturally biodegrade (Cal Recycle, 2010).
- Is aesthetically pleasing and available in various colors (Cal Recycle, 2010).
- Is resistant to insects and bacteria (Cal Recycle, 2010).
- Utilizes plastic waste in landfills. Additionally, in places where plastic sheeting is sent in as relief aid, the materials used to produce RPL are readily available and plentiful.
- Doesn’t use natural resources like bamboo, etc.
- Is less costly than wood in the long term (Cal Recycle, 2010).

### Disadvantages
Using RPL for an inner wall system is unfavorable because:

- The initial cost for RPL is higher than that of wood and therefore may be impractical for relief use (Cal Recycle, 2010).
- Imported technology/equipment is necessary for production (Cal Recycle, 2010).
- Haitian labor may or may not be able/skilled enough to produce the RPL.
- Only certain plastics can be used to produce RPL, reducing ease of assembly and mass of production (Cal Recycle, 2010).

One applicable use of plastic is using it as an adherence onto another method. As with earthbags, placing plastic sheeting on both sides of the wall serves as a protective layer; the plastic will deteriorate from sunlight before the earthbags will. With earth ramming, the plastic can protect the furniture from the large amount of dust that can accumulate from the walls (Rose, 2001). With wattle and daub, plastic can have the same benefits as with earth ramming in addition to appealing to aesthetics. The addition of plastic to these other methods can be done by cutting the plastic to the appropriate size and attaching to the JAS frame with zip ties.

The benefits and drawbacks of using plastic as an addition to other methods are as follows:

### Advantages
Using plastic in accordance with other methods is favorable because:

- It may reduce dust in living space (Rose, 2001).
- Can improve aesthetics.
- Plastic is a readily available resource in Haiti due to relief aid.
- Plastic is recyclable if disposed of properly.
- Installation is simple and can be done with local labor.

### Disadvantages
Using plastic in accordance with other methods is unfavorable because:

- It is permeable to rodents and insects (Howard, 1989).
- Clear plastic degrades quickly when in contact with sunlight and responds poorly to heat (Howard, 1989).
- It may be superfluous, unneeded, and an additional expense.
- It will not enhance the rigidity of other methods.

# 3. Search for Alternative Solutions

## 3.1. Introduction
This section is a compilation of solutions to the stated problem of an insufficient inner wall design. These solutions were produced by both group and individual synthesis of the information collected in the literature review. Its focus is on analysis and creativity, with

minimal additional research. Formulation of the solutions was commenced by two brainstorming sessions: one formal and one informal. In addition to a description of each solution is a diagram to aid comprehension.

## 3.2. Brainstorming

Two brain storming sessions were conducted in order to collect individual ideas and synthesize information gathered during in the literature review. The goal of these collaborative efforts was to begin formulating a solution to the problem described in Section 2 of the project. The first brain storming session was unstructured and had no parameters, allowing members of the group to think freely and express any solution whether it was viable or not. The structured session done next was a branched brainstorm (see Appendices 6.2 for original brainstorming figures). In this brainstorm, the unstructured brainstorm was organized into a bracket system in order to better understand the ideas. Based on the solution variables we brainstormed, we came up with the following designs.

## 3.3. Alternative Solutions

### 3.2.1. Sandwiched Trash

The Sandwiched Trash method utilizes a binding of rigid but thin wire mesh, trash, and zip ties. The wire mesh serves as the outside of the sandwich and can be made out of rigid plastic, if excess from relief aid is available, or even woven sticks. For any of the materials used it is important that the trash remain within the sandwich. This means that the squares in the grid of the wire mesh, plastic, or woven sticks must be adequately small.

Necessary preparation would involve deforming the wire into a flat plate and possibly weaving sticks into the grid in order to decrease the size of the grid squares. Once two plates are assembled, trash is then laid down on top of one of the grids; bricks or a wooden frame may be needed to line the border of the plate in order to contain the trash within the perimeter of the plate as seen in Figure 3.2-1. Then, the second plate is laid on top. Finally, zip ties are used to seal the sandwiched trash, creating a light, rigid, and potentially insulative wall to be fastened to the frame of the structure. Installation of the wall can also be done using zip ties, which is an easy, durable, and low cost method of implementation.

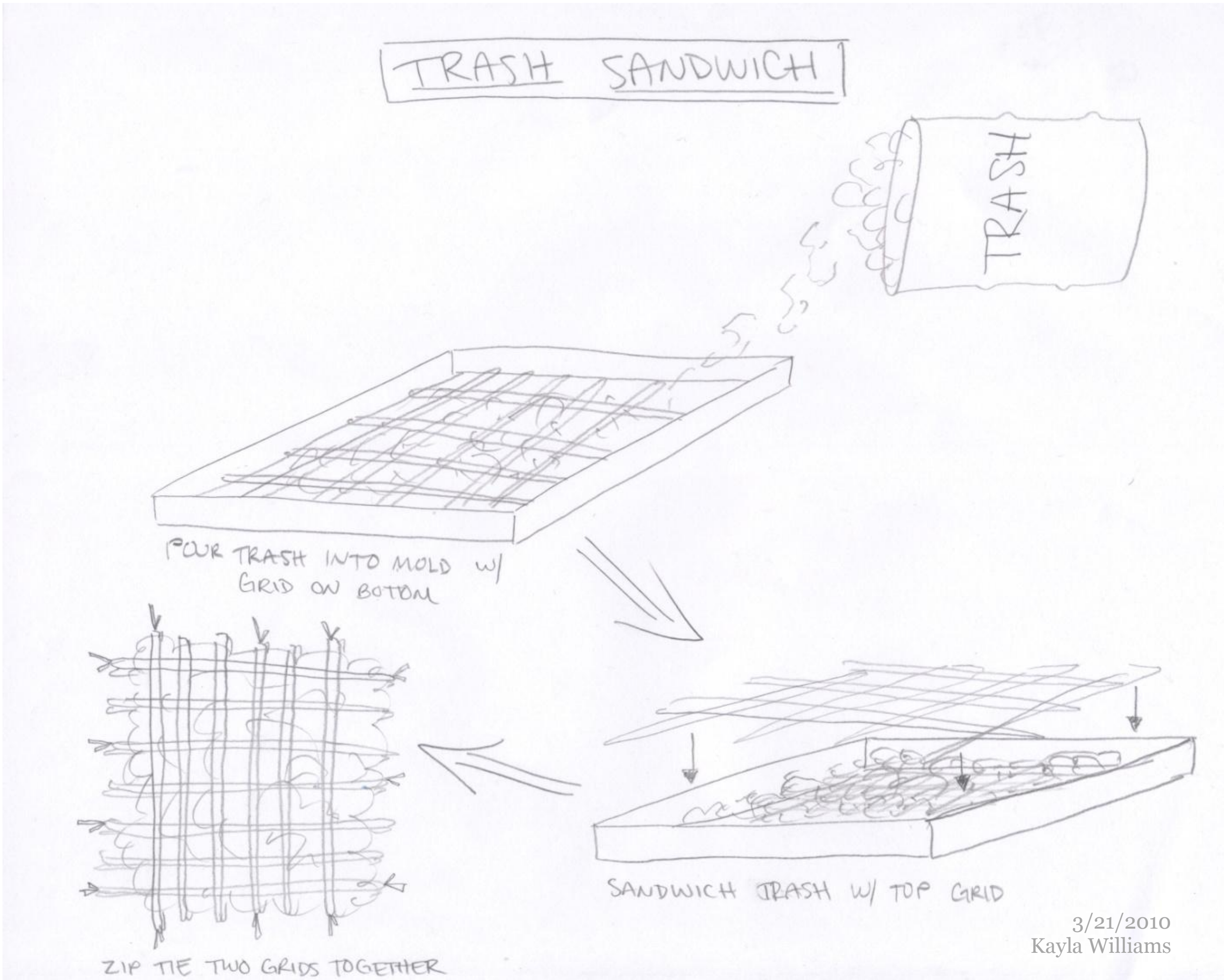



**Figure 3.2- 1: This diagram displays the process required to create a wall out of sandwiched trash.**

This solution's best qualities are its balance between weight and rigidity; this method is in theory very light and rigid with quite a bit of flex. It is also renewable; reusing trash is environmentally friendly, produces no additional waste, and is renewable, making replacement of a wall feasible. Construction is fast, simple, and an opportunity to utilize local labor. As mentioned previously, the wall also has potential insulative qualities. The solution's weaknesses involve mainly a lack of durability; without being sure of the contents of the wall (trash is a composite of many different materials), the life span of the wall is uncertain and can be a concern. Additionally, this method lacks element resistance, and although low cost, there is a cost for the wire and zip ties (or other binding material).

### 3.2.2. Laid Composite

In order to save on costs and essentially utilize the best of many worlds, a mixture of earth, cement, available vegetation, and water (if necessary) can be churned and laid out to dry in a mold made to the dimensions of the desired inner wall as shown in Figure 3.2-2. Before construction, measurements concerning the strength of the material must be taken since previous measurements of the exact composite are likely inaccessible. The addition of a little concrete should theoretically create a strong, rigid wall while still keeping it light and thin. Earth and vegetation are readily available; however, the existence of usable vegetation is questionable considering Haiti's desolation. Earth and vegetation serve as strong substances that can be held together with cement. The mold used to form the shape of the wall while the composite dries can be made out of wood or metal. Ideally the mold should be strong and therefore reusable, reducing cost and materials. The wall would need to be installed into the ground/base of the structure in order to remain stable.

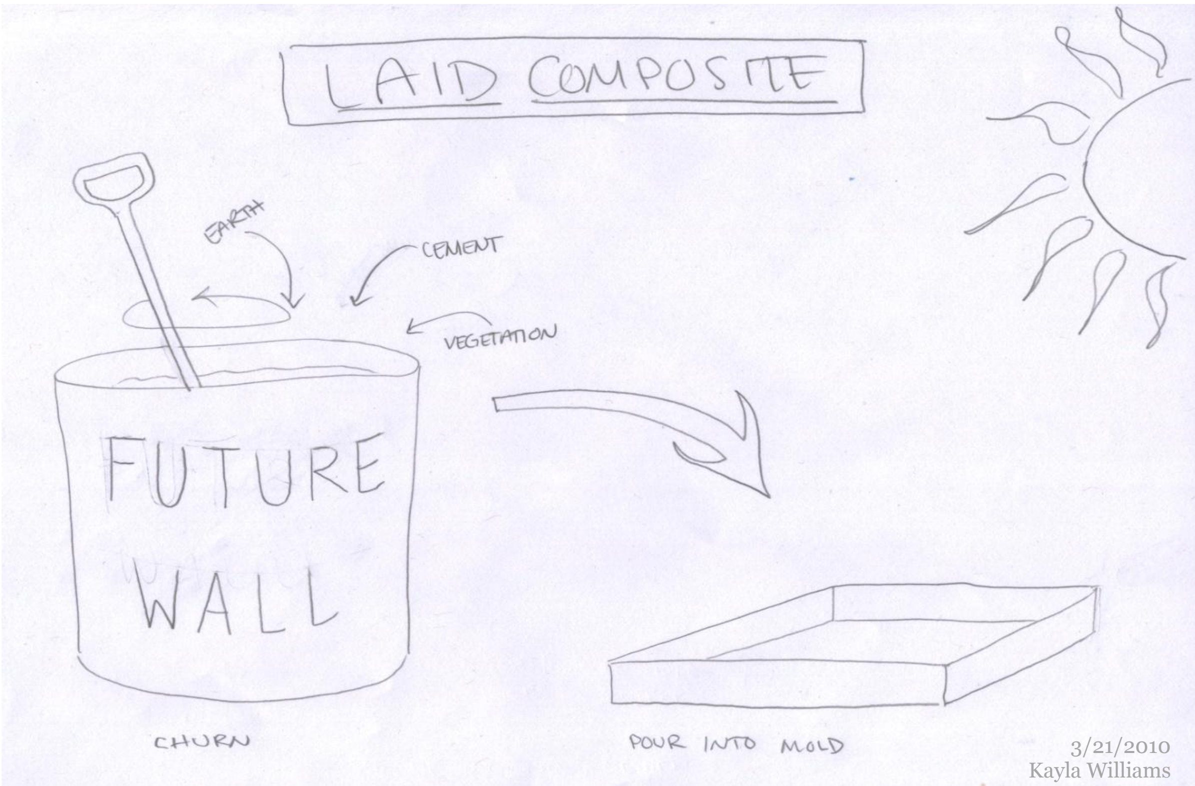



**Figure 3.2- 2: This diagram shows the process needed to create laid composite: churning of the components, pouring into the desired mold, and lay out to dry.**

This solution's strengths rest on its low cost and use of local materials; aside from mixing tools and initial cost of the frame, concrete or cement is the only purchased material. This means that the model is also environmentally friendly and viably replaceable. Insulative value of this method is high, and the rigidity is strong. Local labor can be utilized during construction, which will produce little to no waste. However, this solution is not very light and may have a worrisome lifespan depending on the cohesion of the materials collected on site. Since some strength properties are unknown due to uncertainty concerning the makeup of the composite, fulfillment of the criteria is inconclusive. Depending on the strength of the mix, this method may or may not be a durable and element resistant solution.

### 3.2.3. The Stonehenge

The Stone Hedge involves the use of rubble masonry which is a form of construction that has been used for over a hundred years. First dimensions of the area which the structure is going to take up are taken and then something such as a metal sheath is used to mark off the parameters of the dimensions. Next the mortar (a binding material made from sand, cement and water) is mixed and applied to the stone that should go in that spot. The stone is then placed in that spot, next apply the rubble in horizontal rows applying a generous amount of mortar to each one and putting mortar in between each stone, as seen in Figure 3.2-3. The Stonehenge will substitute the cement in the mortar for limestone and use the rubble readily available in Haiti. The Stonehenge, however would be expensive and difficult to implement in Haiti, whereas most of the materials used are inexpensive masonry is a craft and as result skilled workers would have to be employed to build these homes. As well the limestone used as a substitute for cement in the mortar is a natural resource found in Haiti however it is expensive to mine. Also, the rubble has to be strategically placed in order to ensure that the wall does not fail.

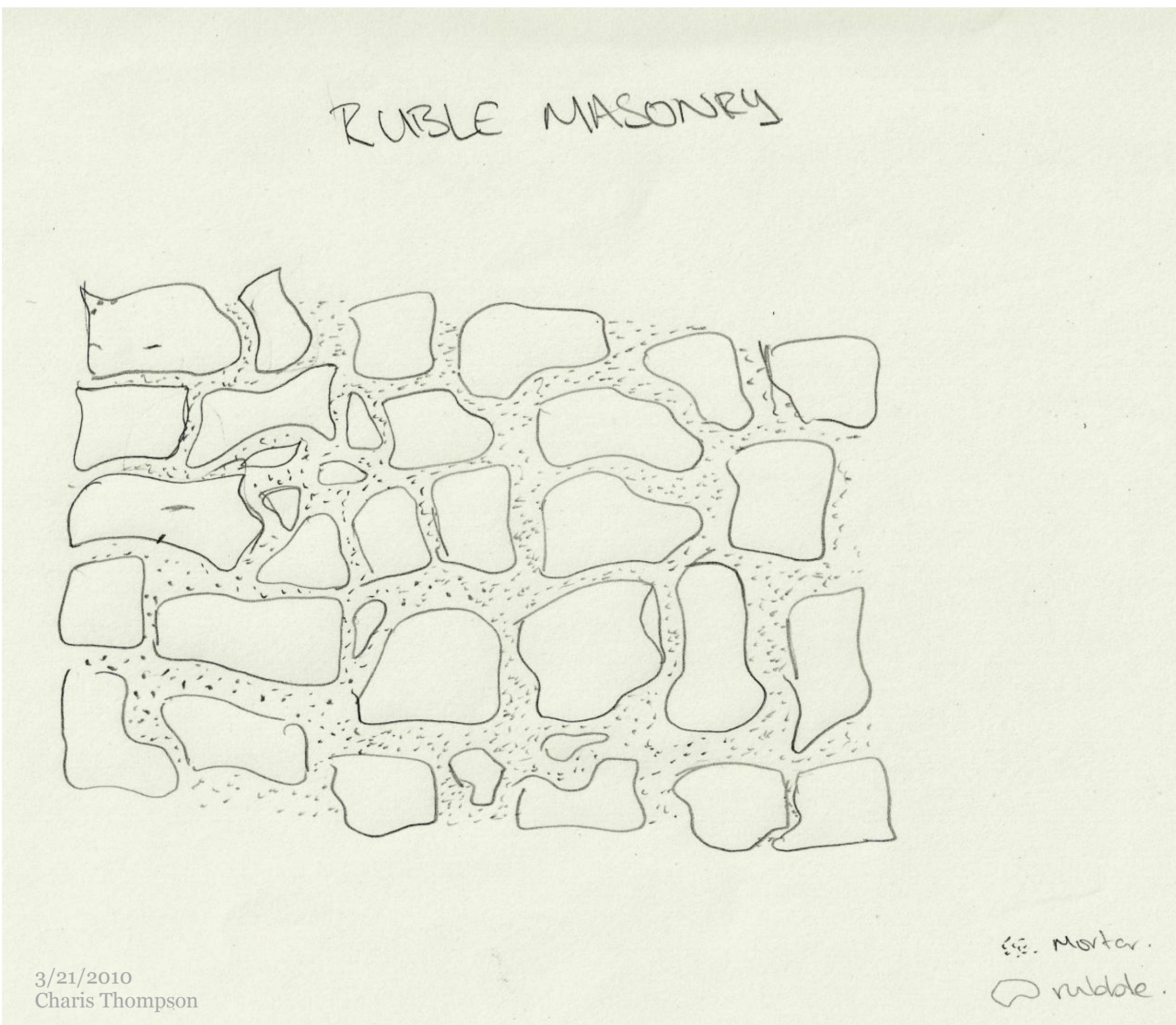



**Figure 3.2- 3: A diagram of "The Stonehenge", a structure made out of rubble masonry.**

## 3.2.4. The Mudenator

The Mudenator utilizes adobe bricks which are an ancient form of construction that have been used from as far back as eighteenth century B.C. They were used by the indigenous peoples of the Americas and can still be found in many countries today such as in Mexico. They are durable, the materials used are cheap, and the bricks are simple to make. First the dimensions of the structure and bricks need to be determined. Once the dimensions are decided upon, the number of bricks needed have to be determined as well. This can be done by dividing the length of the wall by the length of the brick and the width of the wall by the width of the brick. The adobe is then made from a mixture of sand; clay; manure; and water and straw. Once the adobe is made, it is then put inside a long wooden stud (the inside of the stud should be of the same dimensions as the adobe brick). The adobe is then left in the wooden studs to dry for about a week and then removed. The bricks are now ready for construction. They are laid out horizontally and a mortar made of the same material as the brick is used to hold them together, as shown in Figure 3.2-4. After the bricks are made and constructed, the Mudenator will be painted with lime wash in order to increase resistivity to rainfall damage. The advantages of the Mudenator are that adobe bricks are cheap, require little skill to work with, and are durable. However, they are not very insulated and are susceptible to seismic damage.

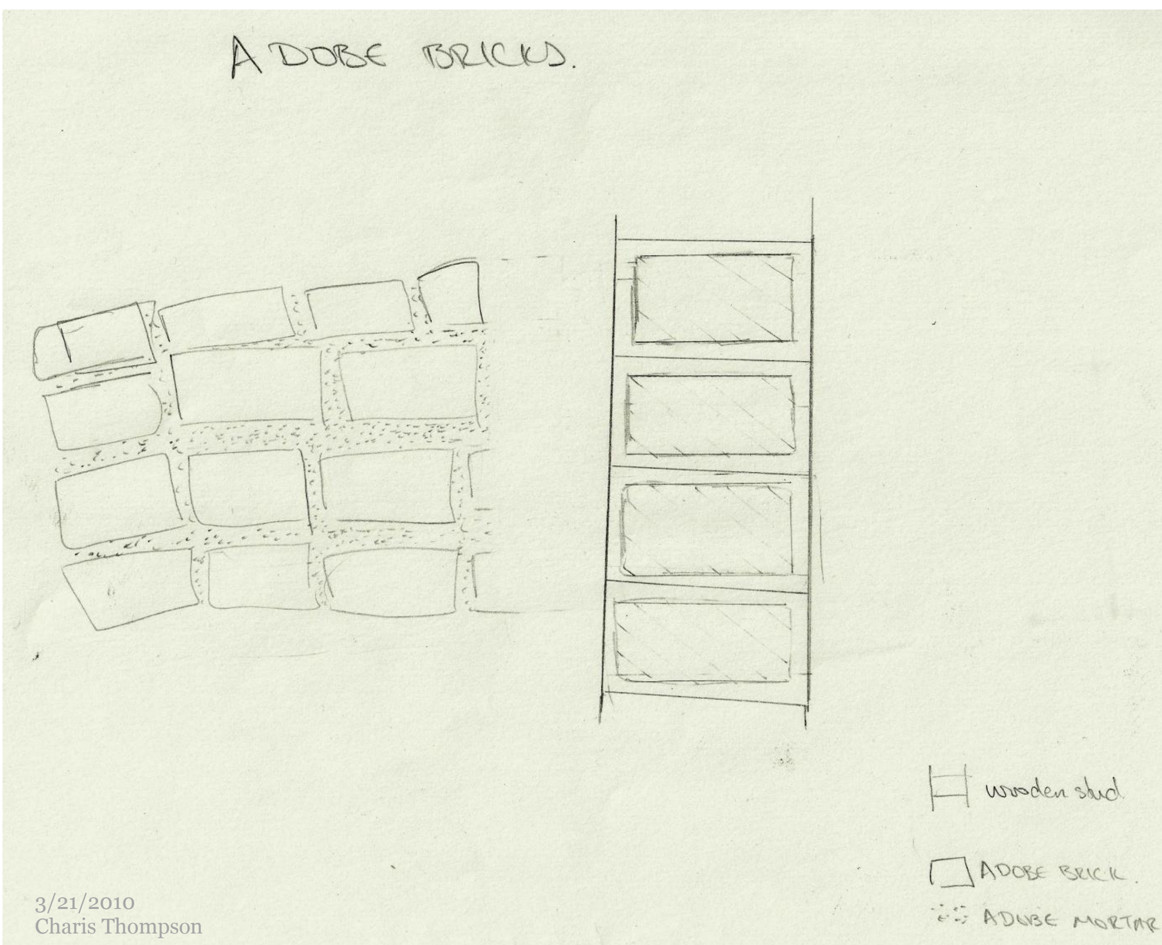



**Figure 3.2- 4: A figure depicting "The Mudenator", a stacking of adobe bricks.**

### 3.2.5. The Mud Pile

The mud pile employs the use of cob which is a building material very similar to adobe. The use of cob can be dated as far back as prehistoric times and these structures can be found in climates all over the World. Cob is a mixture used for building and consists of clay, sand, straw, manure, and water. Cob is similar to adobe, however cob uses about thirty percent more straw. Before building, a frame for the cob has to be constructed. Once the frame is built, the cob is mixed using the correct proportions of sand, clay, straw, manure and water and is traditionally stirred with bare feet. The cob mixture is then added to the frame and compressed using your hands; this is known as cobbing. The house is then left to dry for months and then is inhabitable. The end product of Cob is diagrammed in Figure 3.2-5. Instead of using timber for the frame of the structure, the Mud Pile will employ the use of bamboo or compressed trash, both of which are readily available in Haiti. The mud pile is ideal for Haiti as all materials are cheap and accessible; it requires little skill to construct; is light weight; and is more insulative than adobe bricks due to the hay.

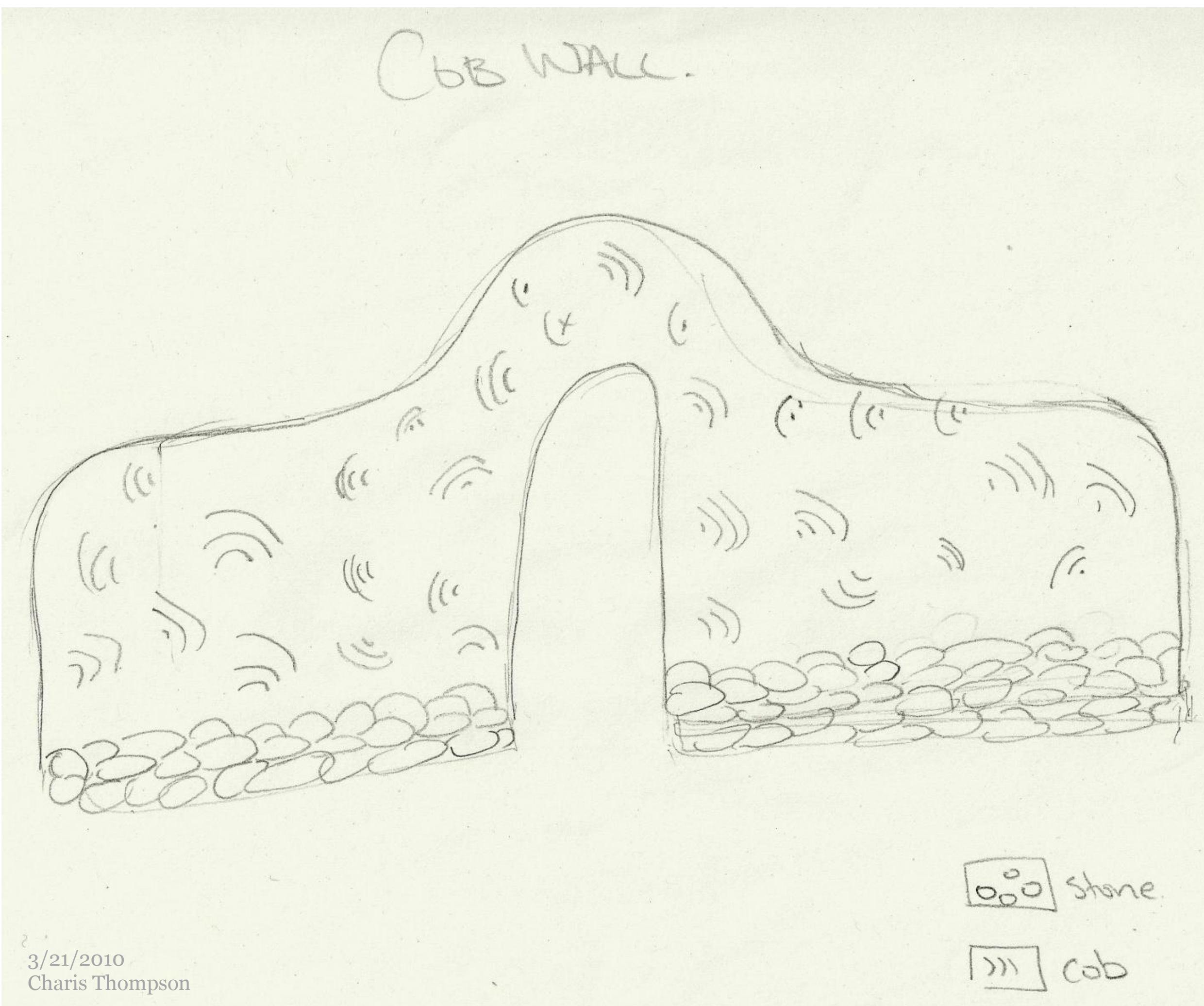



**Figure 3.2- 5: This diagrams the "Mud Pile", or more specifically, a wall made out of cob.**

## 3.2.6. Plastic Bag Weaving

Plastic bags have been used before for many different creative applications, and can function as a primary component in an inner wall. There are two different possible solutions utilizing plastic bag weaving: the simpler one incorporates just sticks, and the other involves wire mesh and heat to aid in durability and rigidity. Both methods are an extension of the concept of wattle and daub.

### 3.2.6.1. Using Sticks

This solution is relatively simple and only includes one major alteration to the traditional wattle and daub. As for the wattle, woven sticks are used as is typical with traditional wattle and daub. For the daub, plastic bags will be used instead. Plastic bags, like trash, are usually disposed of in landfills and their reuse is an advantage of this solution. After the wattle is constructed, the plastic bags are woven through the slots as shown in Figure 3.2-6. The bags should be cut in order to increase tension and length of the weaving material. A standard series of cuts, or prototype, would be used for each bag to increase rate of production, consistency, and ease of construction. The goal of the weaving is to compact as many bags into the grid as possible. This will increase the insulation, rigidity, and durability of the wall. Using plastic bags instead of the clay traditionally seen with wattle and daub not only makes the wall even lighter, but also adding to the appeal of this method. Implementation of the paper bag wall into the structure can be done by looping zip ties or rope through the grid of the wall and around the frame of the structure.

This method is advantageous because of its low cost, ease of construction, and resourceful use of materials. The only costs include zip ties or rope to install the wall into the structure, if plastic bags are available to reuse. Recycling the bags aids environmental conservation as they will most likely end up in landfills. The wall can be replaced, the ease of which is dependent on the simple construction involved; if the bags are damaged, collection of a large amount of plastic bags may be necessary. The ease of construction also allows for use of local labor as well. However, the drawbacks of this solution include lack of element resistance including insects, water, and fire. When heated the plastic will off-gas as well as deteriorate.

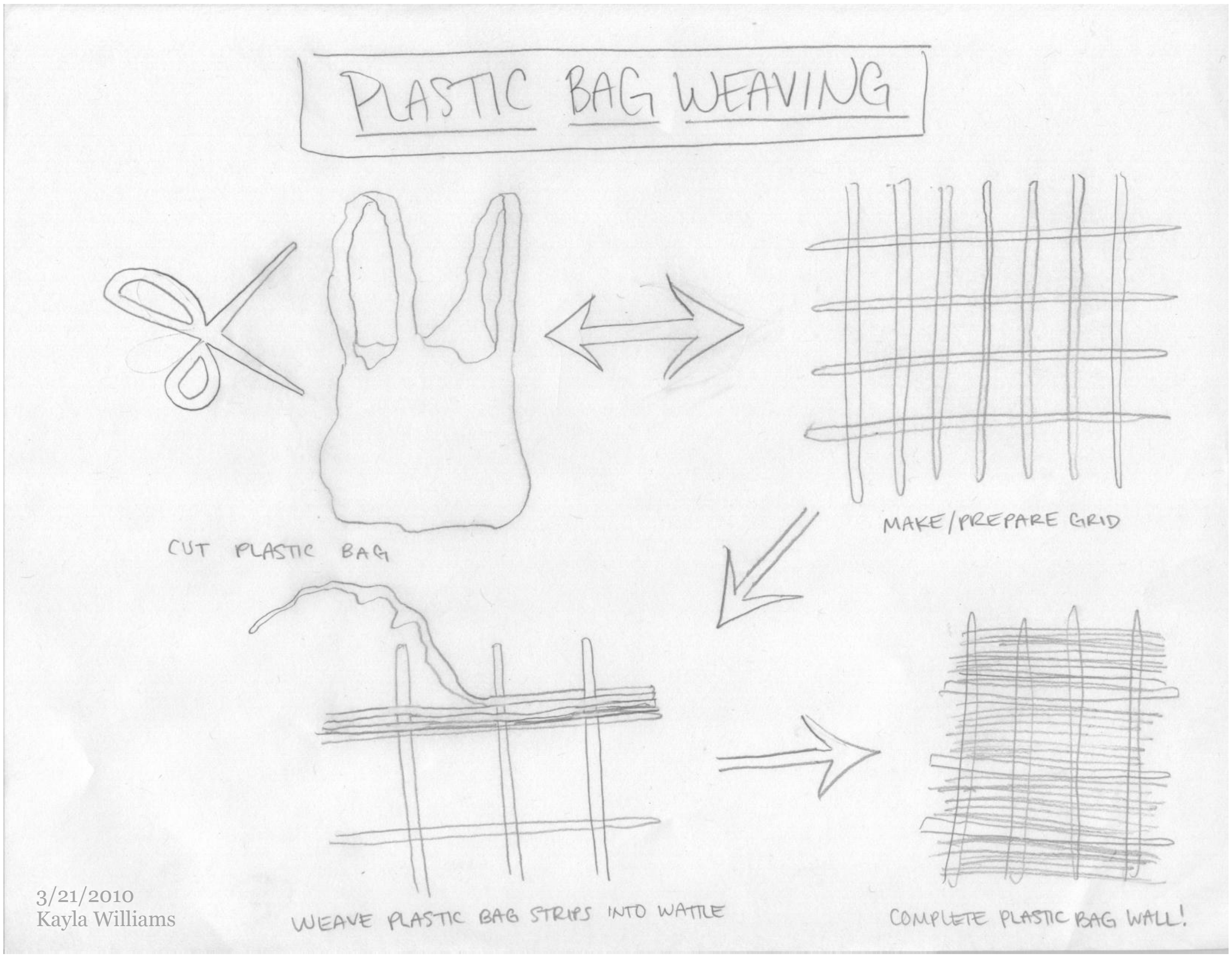



**Figure 3.2- 6: The process of creating a wall out of woven plastic bags.**

### 3.2.6.2. Wire Mesh and Heat

The steps taken to constructing this solution is similar to plastic bag weaving using sticks, only with one additional step: adding heat. Instead of using sticks to create the grid for the wattle, wire mesh is used instead. The size of the grid squares will have to be taken into account when purchasing the wire mesh: the holes must be adequately large so that weaving the plastic bag strips is feasible. After the steps for constructing a plastic bag wall using sticks are completed, heat the plastic using a blow dryer or other device. This will bind the plastic to itself and the wire, creating a rigid film. Heating the plastic compacts the wall, removes air within the plastic, and increases rigidity.

The advantage of heating the wall and using a wire frame as opposed to using sticks is primarily the rigidity of the wall. As a solid film the wall is less impenetrable to insects and water, and the wire allows for flex that aids in surviving horizontal force and high winds. However, one important drawback of heating the system is the off-gas that is produced when the plastic is heated. This is a concern during construction and remains a fire hazard. Additionally, the wire and heating device are added costs which reduce the appeal of the traditionally low-cost solution.

### 3.2.7. Papercrete Sandwich

The Papercrete sandwich is a wire mesh endoskeleton with two Papercrete slabs and a cloth exoskeleton, as shown in Figure 3.2-7. The wire mesh endoskeleton will provide rigidity but still allow for that little bit of flex that is needed for withstanding winds and elements of nature. The Papercrete is responsible for the durability of the system as it shares strength properties with concrete while being a third of the weight of concrete. To improve aesthetics and potentially insulation, the structure will be covered with a local fabric, adding comfort and personality. Fabric can be substituted with plastic sheeting if available and/or desired.

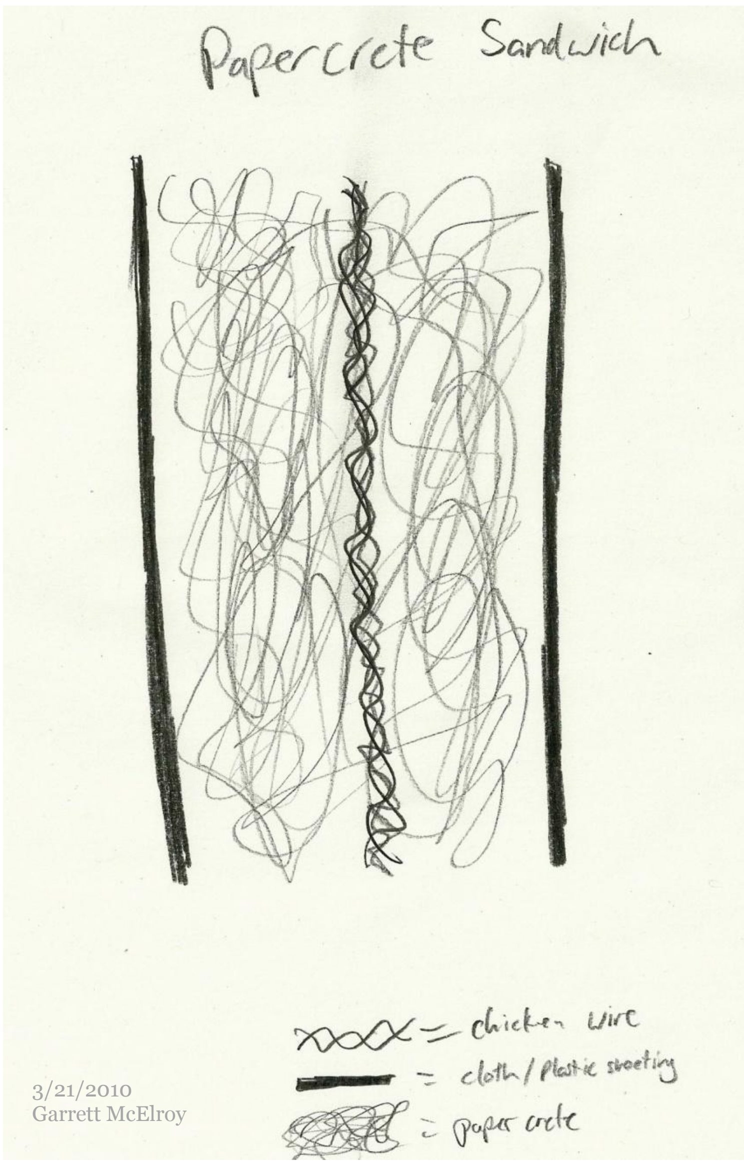



**Figure 3.2- 7: This diagram shows a cross-section of sandwiched Papercrete.**

Papercrete Sandwich is lightweight, resourceful, rigid, insulative, uses local labor, and is element resistant. The addition of paper dilutes the concrete decreasing the weight of the composite, making it about one third the weight of concrete. The use of recycled paper and potentially locally made concrete as a building material is resourceful and allows for low cost. Rigidity comes from the wire core which allows for the flex while supplying strength. Unlike concrete, Papercrete has airspace which provides insulation. Construction of the wall is straightforward but a multiple step process making it a perfect situation for the use of local labor. Element resistance comes from the concrete which withstands fire and water damage.

### 3.2.8. Grass Weave

The Grass Weave, as diagrammed in Figure 3.2-8, consists of a frame made out of bamboo with wire mesh spanning across the opening. The wire mesh is used as the infrastructure of the wall by giving the grass, trash, or bamboo a place to be woven into. Grass and trash are the most commonly used materials due to accessibility and abundance. The grass/trash will allow for a barrier between rooms and will be easy to replace if need arises. The only problem with the Grass Weave is the lack of fire resistance and bug infestation.

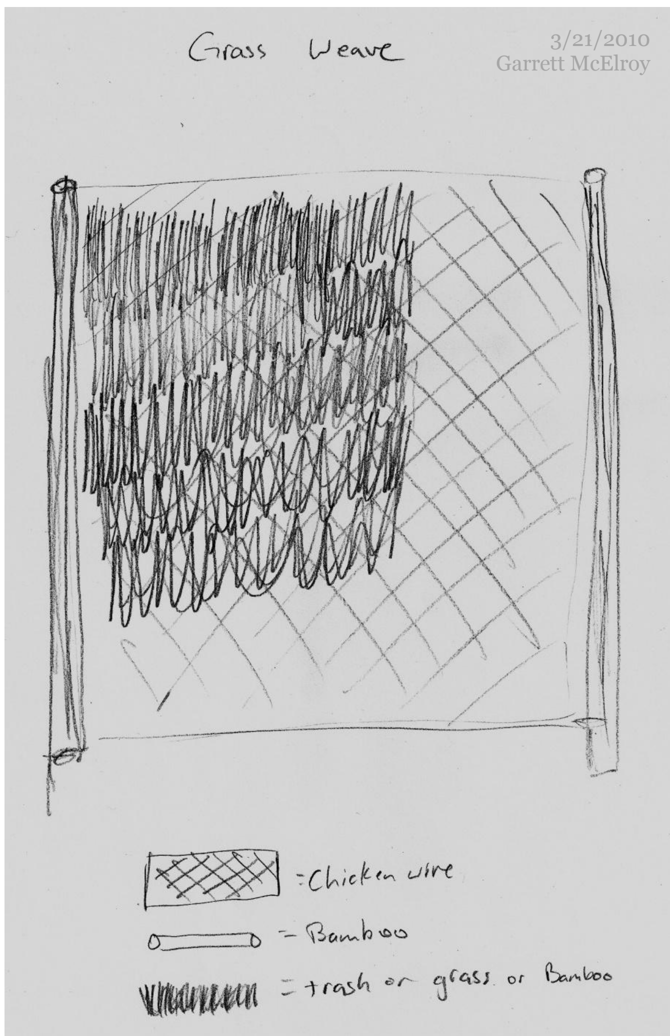



**Figure 3.2- 8: This is a frontal view of the grass weave.**

Grass Weave fulfills some of the criteria stated in Section 2 as it is lightweight, rigid, renewable, and replaceable. Grass Weave's light weight comes from its composition of primarily vegetation, effectually creating air space and lessening the weight. The inner bamboo structure allows rigidity and the chicken wire provides desired flex. Grass Weave is renewable due to local vegetation use, and replacement requires patching with more grass which is a readily available resource in most places. However, this design lacks elemental resistance including but not limited to wire, fire, and wind damage. Additionally, grass weave is susceptible to insect infestation.

### 3.2.9. Bottle Wall

The Bottle Wall in Figure 3.2-9 consists of a cob wall with bottles integrated in to take up space and save material to build other walls. The cob will be Papercrete, which allows for a stronger cob wall as well as reducing weight. The bottles may be laid horizontal or vertical with in the interior of the Papercrete cob wall structure, depending on the desired thickness of the wall. In this design, the bottles used could be plastic or glass, whichever is readily available in the area. This wall system is extremely light weight due to the airspace made by the bottles.

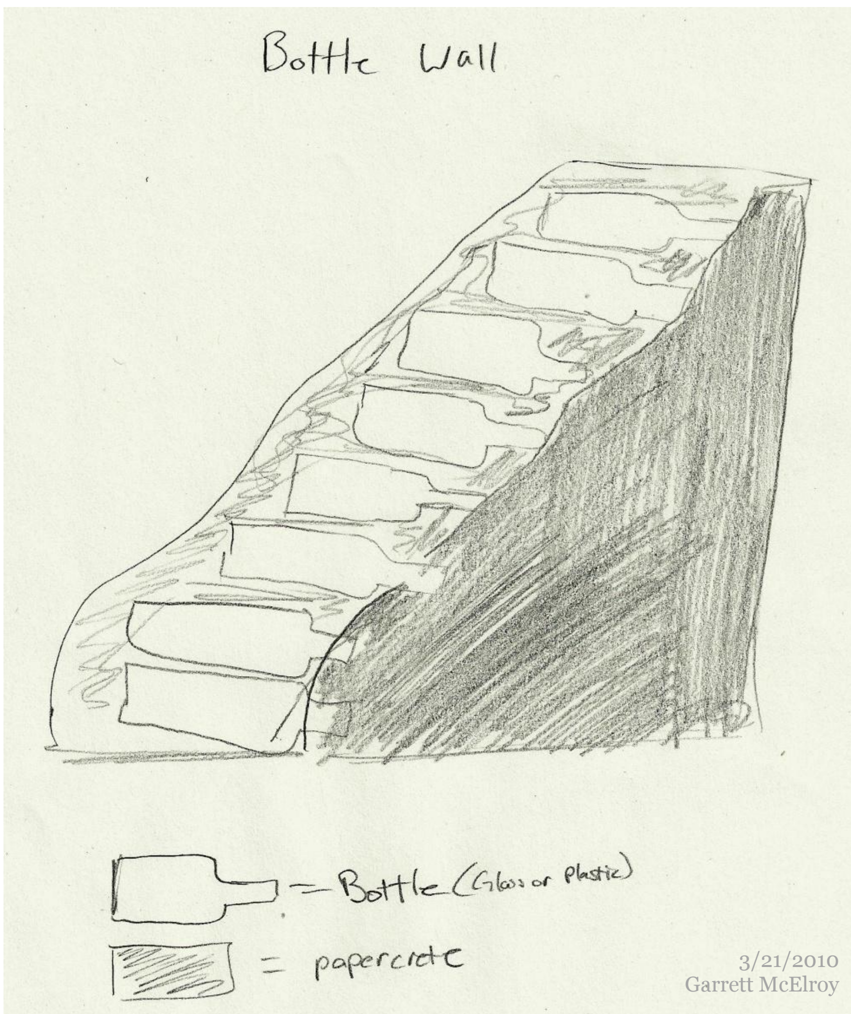



**Figure 3.2- 9: This diagram shows a birds-eye view of a cross section of the bottle wall.**

Bottle Wall is a lightweight, resourceful, rigid, isolative, and element resistant design that utilizes local labor. The main advantage is a result of the empty space within the bottles; this air space lightens an otherwise completely Papercrete wall, which is by itself already one third the weight of concrete. The use of recycled bottles and paper in the wall is resourceful; renewable assuming bottles and paper are commonly recycled/disposed of in the area; and environmentally conscious by reducing contribution to the landfills. Bottle Wall is rigid due to the Papercrete and insulative because of the dense Papercrete surrounding the bottles filled with air. Construction is lengthy but straightforward, making necessary the use of local labor. The concrete in the Papercrete makes this solution fire and water resistant.

# 4. Decision Phase

## 4.1. Introduction

This section outlines the decision making process by which each alternative solution formulated in Section 3 was quantitatively analyzed. This is done by rating the criteria established in Section 2 on pertinence and/or importance and then employing the Delphi method to decide on the best solution for the established criteria.

## 4.2. Criteria Definition

The following, in no particular order, is a list of the criteria used to evaluate each of the alternative solutions.

- **Zero Cost Goal:** Spending for this project will be next to nothing due to prioritization of all World Shelters projects. Therefore, it is necessary to utilize free or negligible cost building materials, transportation and construction inclusive.
- **Long Lasting:** The project's findings will double as a resource for other World Shelters projects. This project should increase the requested life span of the system from a couple years (relief) to as long as is feasible (lifetime).
- **Rigid and Durable:** The wall system requires rigidity so it has the functionality of a normal inner wall structure, the wall will not have to bear load but must withstand normal living conditions.
- **Local Labor Use:** Utilization of the Haitian work force drives self-sufficiency, reduces foreign dependency, and may possibly create more jobs.
- **Ease of Assembly:** The procedure for construction of the wall must be understandable by Haitian laborers. The number of workers required is irrelevant to this criterion, but the mental and physical exertion necessary for construction must be minimal.
- **Element Resistant:** Must withstand degradation from surrounding elements as well as possible hazards like fires and hurricanes.
- **Insulative:** The wall should resist thermal conduction
- **Lightweight:** The structure should maintain a lower mass which would increase safety.
- **Aesthetics:** The structure should be visually appealing as it may later be used for family housing.

## 4.3. Solutions

The following is a list of the alternative solutions formulated in Section 3:

- Plasticbag Weaving (Wire&Heat)
- Plasticbag Weaving (Twigs)
- Trash Sandwich
- Papercrete Sandwich
- Grass Weave
- Bottle Wall (Papercrete)
- Mud Pile
- Stonehenge

Section 3 provides a description of each method.

## 4.4. Decision Process

The Delphi method was chosen to help reach a final decision. The Delphi method requires a list of weighted criteria (outlined in Section 4.5) that is then compared to each potential solution. Then each solution must be rated according to that criterion; we chose to rate out of 100, this step required a thorough analysis of each aspect of the solution. It is critical that each assigned rating be as accurate as possible and additional research should be done if necessary. After each score is chosen, it is multiplied by its respective criterion rating and that product is the number under the slash this can be seen in Figure 4.4-1. Then each column is totaled and the solution with the highest value is the deemed the best method according to the criteria. The findings, shown in Figure 4.4-2, must be analyzed and human error must be accounted for with regards to rating each of the criteria. Although this method does not provide a final decision, it is a focal piece in the decision process and the results from this method are pivotal to further evaluation.

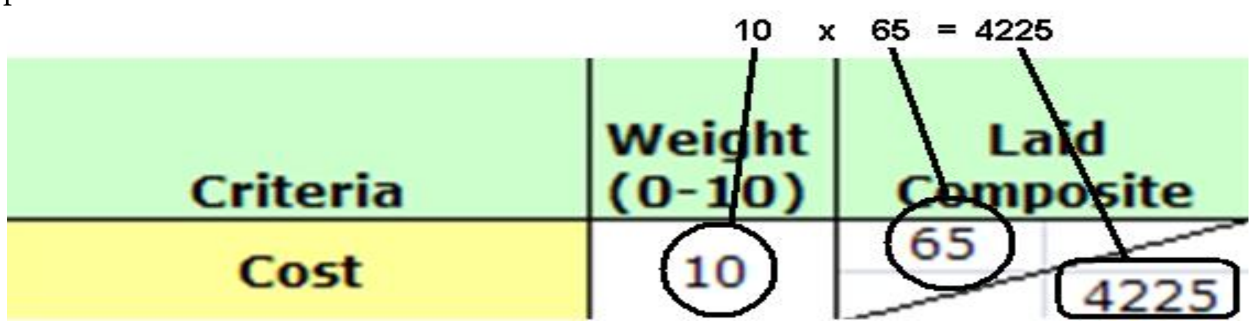



**Figure 4 - 1: This rough explication illustrates the multiplication executed by excel that produces all the values under the each of the assigned values.**

| Criteria | Weight (0-10) | Laid Composite | Plasticbag Weaving (wire+heat) | Plasticbag Weaving (twigs) | Trash Sandwich | Papercrete Sandwich | Grass Weave | Bottle Wall (papercrete) | Mud Pile |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 10 | 65 / 4225 | 60 / 3900 | 75 / 4875 | 60 / 3900 | 65 / 4225 | 50 / 3250 | 50 / 3250 | 40 / 2600 |
| Longevity | 9 | 50 / 450 | 75 / 675 | 75 / 675 | 40 / 360 | 90 / 810 | 50 / 450 | 75 / 675 | 35 / 315 |
| Rigidity | 10 | 65 / 650 | 75 / 750 | 50 / 500 | 50 / 500 | 90 / 900 | 50 / 500 | 80 / 800 | 55 / 550 |
| Lightweight | 7 | 50 / 350 | 80 / 560 | 90 / 630 | 90 / 630 | 35 / 245 | 80 / 560 | 40 / 280 | 35 / 245 |
| Local Labor Use | 9 | 80 / 720 | 35 / 315 | 15 / 135 | 20 / 180 | 90 / 810 | 15 / 135 | 90 / 810 | 20 / 180 |
| Element Retardant | 9 | 80 / 720 | 65 / 585 | 50 / 450 | 60 / 540 | 90 / 810 | 50 / 450 | 75 / 675 | 80 / 720 |
| Insulative | 5 | 70 / 350 | 40 / 200 | 40 / 200 | 50 / 250 | 85 / 425 | 70 / 350 | 90 / 450 | 85 / 425 |
| Aesthetics | 3 | 30 / 270 | 50 / 450 | 30 / 270 | 15 / 135 | 50 / 450 | 25 / 225 | 45 / 405 | 40 / 360 |
| Ease of Assmebly | 5 | 65 / 325 | 80 / 400 | 80 / 400 | 75 / 375 | 55 / 275 | 70 / 350 | 60 / 300 | 80 / 400 |
| TOTAL | | 8060 | 7835 | 8135 | 6870 | 8950 | 6270 | 7645 | 5795 |

**Figure 4 - 2: The final Del Phi method chart. The cells highlighted in yellow are the criteria, and the pink columns are the solutions we *initially* preferred.**

Below is the list of weighted criteria employed in the Del phi method chart. World Shelters representative, Kurt Therkelsen aided in rating each of the criteria. Cost and rigidity were deemed the most important criteria as they are related to feasibility and structural stability, respectively.

| List of Weighted Criteria | |
|---|---|
| Cost | 10 |
| Rigidity | 10 |
| Longevity | 9 |
| Local Labor Use | 9 |
| Element Resistance | 9 |
| Lightweight | 7 |
| Insulative | 5 |
| Ease of Assembly | 5 |
| Aesthetics | 3 |

## 4.5. Final Decision Justification

The Del-phi method was used to help select an appropriate final solution. Beginning the final decision process, there was not a leading or favorite design. After much discussion on the outcome of the del-phi method, it was concluded that the highest rated design, Papercrete Sandwich, would be the basis for the final design. The Del-phi method a very useful way to compare each solution and identify which design best met the important criteria.

After speaking with the client and discussing the advantages and disadvantages of each solution, a hybridization of two solutions was identified as the final design: Papercrete Sandwich and Laid Composite. Even though the Plastic Bag Weaving Using Sticks was a more probable solution than Laid Composite according to the Delphi matrix, it was decided that Laid Composite would be a more appropriate solution. This decision was based upon the need for the design to be resourceful; Laid Composite employs the use of dirt which is a readily available resource in Haiti, whereas Plastic Bag Weaving Using Sticks employs the use of plastic which is not as readily available in Haiti. Additionally, the hybrid of Papercrete Sandwich and Plastic Bag Weaving loses some of the strengths of each original design. For example, if Papercrete is used as additional coating for Plastic Bag Weaving Using Sticks, the wire core innovation of a Papercrete Sandwich is lost for the minimal gain of possible additional strength in the new hybrid design. Lastly, Plastic Bag Weaving Using Sticks involves melting plastic on to the structure with the application of heat which would reduce the fire resistance of the Papercrete Wall; when already melted plastic is reheated, toxic fumes are off-gassed molten plastic is produced, transferring heat. Laid Composite, on the other hand, shares design characteristics with Papercrete Sandwich, making a practical combination. One advantage of hybridizing the two designs is reduction of the construction costs, one of the most heavily weighted criteria, by using less cement. The dilution process present when creating Laid Composite will reduce the ratio of cement to other elements in the Papercrete mixture. In the next phase we will resolve the specific proportions and makeup of the final solutionthrough material testing.

# 5. Specification of Solution

## 5.1 Introduction

Section 5 describes the testing and results of the final solution for project Make It Complete With Papercrete: a Papercrete wall with a wire core enhancing rigidity, as shown in Figure 5-1. Prior to the formulation of this section, a small scale model of the wall was built and then tested with a concentration placed on the conditions and hazards typical to Haiti. This culmination includes an analysis of the physical product, steps for implementation, a cost outline for construction, and the final results testing durability.

## 5.2. Solution Description

Section 4, or otherwise known as the Decision Process phase, led to the final product of the design project: the Papercrete Sandwich. In this section, the final design is outlined with more detail than in Section 4. In order to better represent the final product and for professionalism purposes, the final design name was changed from Papercrete Sandwich to Papercrete Wall.

### 5.2.1. Properties

The designed inner wall system incorporates the use of Papercrete, a weatherproof and fire resistant material. Papercrete makes use of the fibers found in paper and durability in concrete to form a rigid structure. The Papercrete Wall involves a wire mesh endoskeleton, providing the rigidity while allowing flex within the wall piece which provides protection from winds and the elements of nature. The Papercrete exoskeleton is an imperative piece to the final solution as it supplies the innovation and durability that sets this design apart from other inner wall systems typically found in long-standing and relief structures. The Papercrete component provides the insulation, wind and water proofing, fire resistance, and the desired durability while maintaining a lightweight configuration.

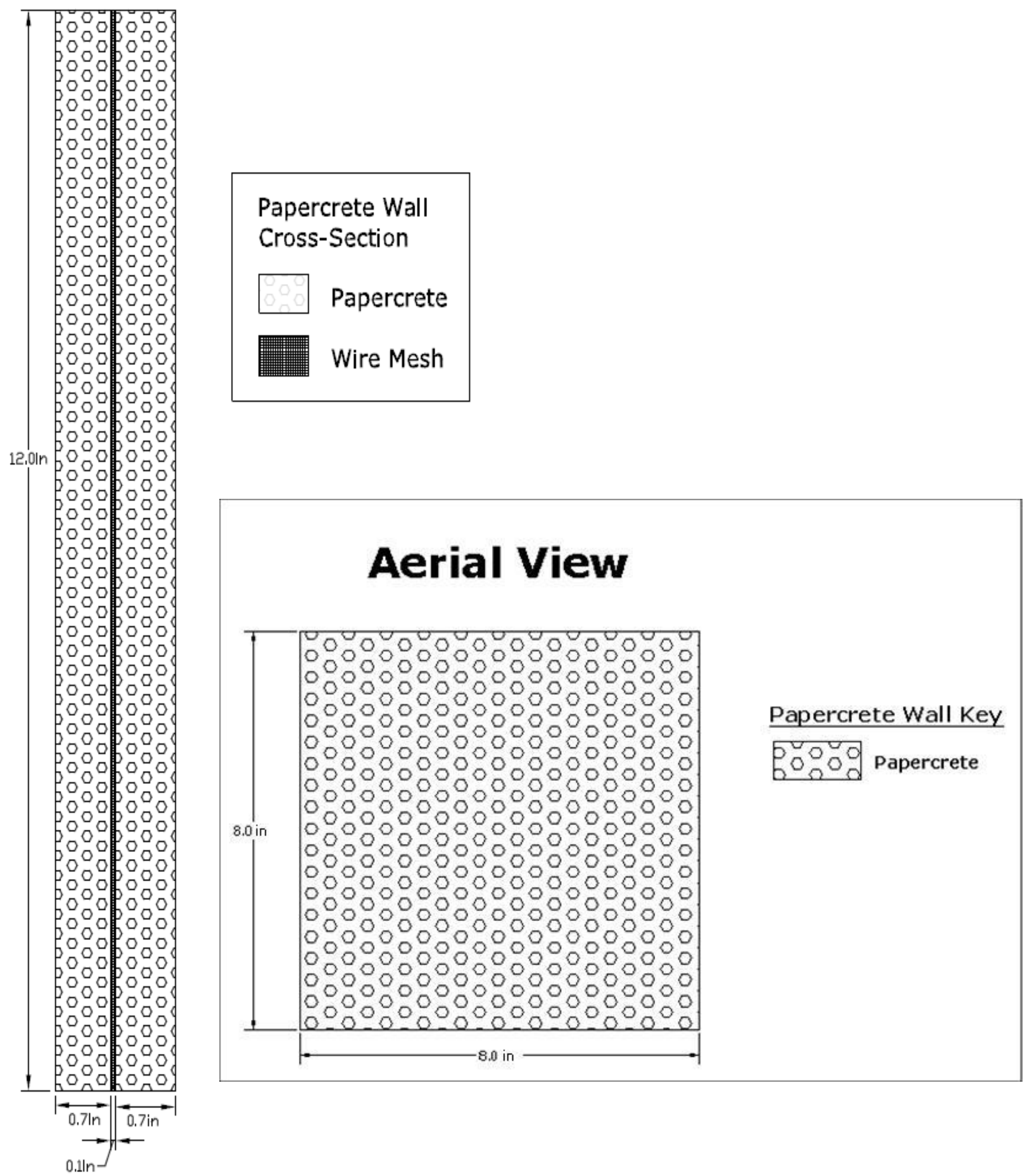



**Figure 5 - 1: These two CAD drawings provide a cross-section and aerial view of the Papercrete wall, with exact dimensions scaled from feet to inches and material representative.**

Papercrete maintains many of the properties characteristic of concrete while being only a third of the weight of normal concrete. The wall itself is 1.5 inches thick, allowing for the desired thin frame and tensile strength. The surface area can be as large as needed for the structure. When taking into consideration the most durable and cost effective design, the recommended Papercrete ratio is 1:3 (one part paper to three parts cement). However, if desired, other ratio options are possible.

### 5.2.2. CONSTRUCTION

Building a Papercrete wall involves the following steps: 1)constructing the frame 2)mixing the Papercrete 3)pouring the mold 4) compressing the mixture, and 5)drying. If provided instructions and executed with efficiency, the building can be done in half an hour with the drying time dependent on the climate, weather conditions, and time constraints.

The materials and tools used to construct the frame include wood, screws, a drill, a saw, and band clamp (optional). First, cut four pieces of wood that are one inch thick, about three inches deep, and the length of the dimensions of the desired wall. Then cut the ends of the four pieces of wood at an angle of 45° along the one inch side; strap the four sides so that the slanted ends fit together using the band clamp if available; screw the four pieces together into a square; and remove the band clamp (if used). Now add the bottom of the frame. Cut the baseboard of the frame out of one slat of wood which has the dimensions as the desired wall with an additional inch on every side. Place the slat of wood on top of the frame and attach at four corners with screws. Then flip the frame over and the frame should have a similar shape as the frame shown in Figure 5-2. Now begin the process of mixing the Papercrete.

**Figure 5 - 2: The end product of the frame. This frame is 3 ft x 3 ft and 3 inches deep (Williams, 2010).**

Before mixing the Papercrete, the ratio of paper to concrete must be decided. The needed materials inlude: a scale; a mixing bucket; pounds of paper; concrete; water; drill with mixer drill bit; and wire mesh with the dimensions equal to that of the eventual wall. The paper and concrete should be weighed out to the previously decided ratio. If working with a small mixer, the paper should be shredded before added to the mix. This can be done easily however laboriously by hand. Place the appropriate weight of paper and concrete into the bucket and add just enough water to make a slurry. The amount of water does not need to be precise, just thick enough to be moved around by hand. Additionally, excess water will be drained out through compression or will evaporate with time. Mix the contents in the bucket using the drill and the mixer drill bit, or any mixing device available. Mix until the paper is ground up and the slurry looks homogenous.

**Figure 5 - 3: Here captures the last step of the laying process: setting the second coat of Papercrete (Williams, 2010).**

The mold is then laid into the frame previously built. First place the mixture into the mold so that the base is covered with Papercrete. The wire mesh should then be placed on top of the mixture; lay the wire flat on top of the Papercrete so the mold will dry flat. Lastly, add a second layer of Papercrete on top so no wire is visible. The system should then be left to dry.

Compression is one innovation to the Papercrete Wall design. Compressing the mixture with a sheer force allows for a shorter drying time and a more compacted product and is vital for increasing rigidity. Compression can be done simply by placing a slat of wood the dimensions of the wall on top of the laid mold inside the frame. The system should then be compressed using any effective tool available; one method is creating a ramp with a piece of wood and driving over the system. For a small sample, one option involves placing the mold between a car and a car jack; the weight of the car acts a sheer force on the frame as seen in Figure 5-4. This will drain out almost all of the water; the remaining water will evaporate upon standing.

**Figure 5–4: The weight of the car compresses the mold and drains all of the excess water (Williams, 2010).**

## 5.3 Cost Analysis

### 5.3.1. Design

The design costs incorporate a culmination of the amount of working hours logged by the design group throughout the course of the design project. The total amount of hours accumulated was 218. Figure 5 – 5 displays the percentage of the total group hours that was spent on each phase of the design project.

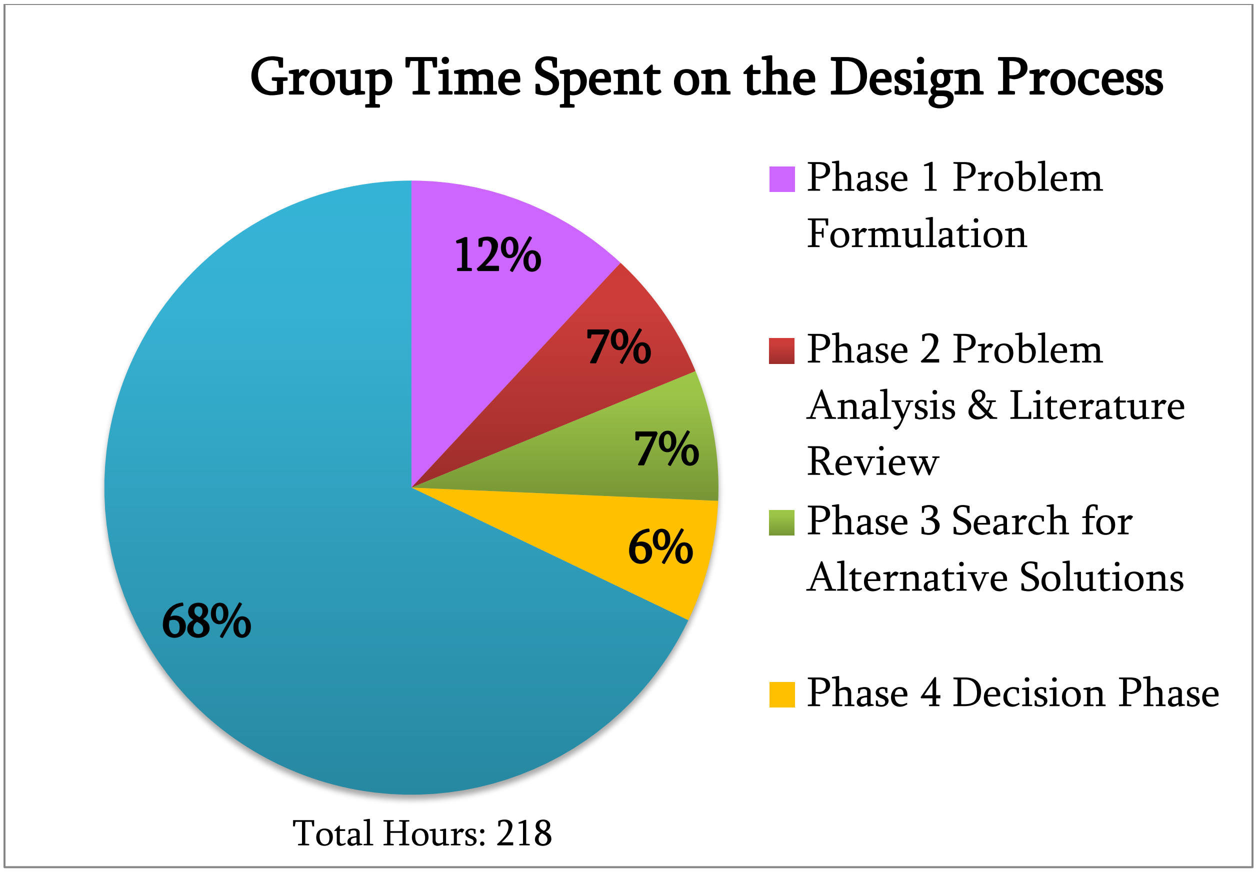



**Figure 5 - 5: This model breaks down how much group time was spent on each phase in the design process.**

### 5.3.2. Construction

This section includes an analysis of the cost required to construct the final design. Table 5-1 below lists the materials used and their respective costs. Cost of transportation of the materials was neglected because they are not representative of those in Haiti; the transportation costs will likely only include any costs for importation of materials. All costs pertaining to lessening the drying time were neglected; Haiti's climate will be sufficient in aiding the drying process. As shown in the table, a total of $40.55 was spent on construction of multiple small scale models.

**Table 5 - 1: This breaks down the cost of all materials used to build the model. Values are in USD.**

| Item | Amount | Cost | Total |
|---|---|---|---|
| 1/2in Steel Wire mesh | 6 | 1.19 | $7.14 |
| 8'x4' Piece of Plywood | 1 | 14.98 | $14.98 |
| Concrete 60lb Ready Mix | 1 | 3.99 | $3.99 |
| Pine Board 1"x4"x12' | 1 | 5.6 | $5.60 |
| Wood Cuts | 3 | 0.5 | $1.50 |
| Drill Paint Mixer | 1 | 2.99 | $2.99 |
| 1/4lb Screws | 1 | 1 | $1.00 |
| **Sales Tax:** | | | $3.35 |
| **Total:** | | | $40.55 |

### 5.3.3. Maintenance

There is value in assessing the cost required to maintain the inner wall system. Possible failings in the wall could be the Papercrete pealing off the wire framework or severe cracking. If this happened, patching up the wall would normally be a sufficient fix. To do this, take the following steps.

1. The pieces of Papercrete that are separated from the wire should be taken off and thrown out.
2. A sharp utensil should then be used to rough up the remaining wall until the surface is coarse.
3. A new batch of either Papercrete or concrete should be mixed as it will be used to patch the wall. If Papercrete is being used to patch the wall, the ratio of cement to paper should be larger than the ratio in the original wall.
4. The wall should then be patched with the Papercrete or concrete mixture. The mixture can be applied by hand or applied with a smooth straight surface to ensure the wall is flat. The water content of the mixture must be taken into account since the mixture must be thick enough to adhere to the wall on its own. Note: When using concrete, it may be necessary to press a smooth surface against the wall during the drying process by propping a stick at an angle to hold the surface in place.
5. The wall should be left untouched until completely dry. If available, a fan or a space heater may be used to assist the drying process.

If the damage to the wall is unfixable by means of patching, replacement of the whole wall is necessary. To do this, the zip ties that attach the wall to the structure must be cut followed by removing the wall. If the wire mesh is undamaged it may be reused. From there, the process initially followed to construct the original Papercrete wall must be repeated.

Action may also be taken to prevent damage. Covering the wall with cloth, tapestries, etc. to protect from sunlight may increase the lifespan of the wall and prevent cracking. Large horizontal forces that may deform the wall should be avoided.

## 5.4. Implementation Instructions

Implementation of the wall involves attaching the wall to the frame of the structure. This will increase the durability of the wall. The only tools needed are a drill and preferably zip ties, although any type of strong rope or string will suffice. First, holes need to be drilled in the wall about six inches apart and two or three inches from the edge. The zip tie or rope should then be laced through the holes and tied to the frame. The wall should sit on the base of the structure to take strain off of the ties so the structure may instead rely on the strength of the Papercrete wall.

## 5.5. Prototype Performance

Three tests were conducted on a model of one part paper to four parts concrete in order to test the properties of Papercrete. Through the research conducted in Section 2, Papercrete was deemed to be fire resistant, insulative, and strong. The purpose of the tests were to validate each of these researched properties; therefore flame, insulation, and strength tests were performed.

### 5.5.1. Flame test

Our prototype with the ratio of four parts concrete to one part paper was used to perform the flame test. Once the prototype was made and dried, a flame test was done by holding it next to a 10,000 BTU flame for a period of 2 minutes. The prototype appeared to be fire resistant; the surface of it charred, however the material neither corroded nor disintegrated. During the flame test the gravel in the concrete began to pop out due to the high heat. Sifting out the gravel from the concrete before making the Papercrete would remedy this hazard as well as reducing conduction within the wall.

**Figure 5-6:** **Results from the flame test (McElroy, 2010).**

### 5.5.2. INSULATION TEST

This test was also conducted with a 10,000 BTU flame. After two minutes and thirty seconds of heating the sample, a laser thermometer was used to take the temperature of the side being heated. The laser thermometer showed that the heated side was heated up to 587 °F while the unexposed side was only 104 °F. A hand was placed on the unexposed side periodically during and after the two and a half minutes of heating; it was noted that the model felt cool to the touch each time, as displayed in Figure 5-7.

**Figure 5-7: The side of the sample unexposed to heat remained cool during heating (Thompson, 2010).**

### 5.5.3. TENSILE TEST

The tensile test was done by suspending the model between two tins of paint. One five pound brick was placed on top the model, followed by a thirty pound cinder block. With a total of thirty-five pounds, the wall flexed but supported the weight. Five pound bricks were then added one by one until the model began to crack. As shown in Figure 5-8, the sample wall supported fifty pounds before it cracked. These results were favorable; not only was the sample only an inch and a half thick, but the designed inner wall system will not need to bear load. However, the test verified the strength of the design, confirming that the wall will withstand horizontal loads with a cap somewhere around fifty pounds force.


**Figure 5-8:** **The Papercrete model suspended on paint cans supported a fifty pound load (Williams, 2010).**

### 5.5.4. Results

Testing verified the researched strengths of Papercrete as well as introducing an additional innovation that would improve the final design. Sifting out the gravel in the concrete prior to mixing the Papercrete reduces the conduction in the wall, effectually reducing the hazard of gravel popping out when exposed to high heat. Additionally, removing the rocks would reduce the weight of the wall and increase the ratio of cement to sand within the concrete; this improves adhesion and chemical bonding between the elements because the proportion of cement is increased.

# 6. APPENDICES:

## 6.1 REFERENCES

6.1.1. Hart, K. *Earthbag*. Retrieved on February 24, 2010, from Green Home Building website: http://greenhomebuilding.com/earthbag.htm

6.1.2. US Army Corps of Engineers. *Flood Fighting: How to Use Sandbags*. Retreived from http://www.bhs.idaho.gov/Resources/PDF/Flood_Fight_How_To_Use_Sandbags.pdf

6.1.3. The United States Department of Agriculture: Natural Resources Conservation Service (NRCS). (August 2000). *Sandbag Barrier*. http://www.beavertonoregon.gov/departments/emergency/Resources/docs/flood_Sandbag.pdf

6.1.4. Portland Cement Association. (2010). What is White Portland Cement? Retrieved: January 2010, from http://www.cement.org/decorative/about.asp

6.1.5. Living in Paper. (2007) Mixes Retrieved : January 2010, from http://www.livinginpaper.com/mixes.htm

6.1.6. Timhp.2005 . Papercrete in Mold. (April 27,2010) http://www.flickr.com/photos/7501669@N04/436034784

6.1.7. Rob Sanders Custom Home & Remodel Design - Austin & Central Texas. (2009) Papercrete Block Construction. Retrieved January 2010, from http://robsandersdesigner.blogspot.com/

6.1.8. County of San Bernardino: Economic Development and Public Service Group. (January 2004). *Debris and Erosion Control*. Retrieved from http://www.sbcounty.gov/floodinfo/DebrisandErosionBooklet.pdf

6.1.9. Rose, Owen. World Commission on Environment and Development. *Our Common Future*, Materials: Earth. (March, 2001). Retrieved at http://www.ecosensual.net/drm/eco/ecoearth1.html

6.1.10. Cal Recycle. (February 03, 2010). *Recycled Plastic Lumber*. Retrieved at http://www.calrecycle.ca.gov/Plastics/recycled/Lumber/

6.1.11. Howard, Jim. Plastic Sheeting: Its Use for Emergency Shelter and Other Purposes. (May, 1989). Retrieved at http://plastic-sheeting.org/ref/Plastic-Sheeting-revision3-1989-web.pdf

6.1.12. Samaritan's Purse. (January 23, 2010). *Help For Quake Victims*. Retrieved at http://www.samaritanspurse.org/index.php/articles/responding_to_haiti_earthquake/

6.1.13. Bill & Stephen Betzen,(2006) DIY Rammed Earth. Retrieved January.2010 From http://www.diyrammedearth.com/

6.1.14. Rammed Earth. (2010) What is rammed Earth? Retrieved January,2010 From http://rammedearth.org/index.php?option=com_content&view=article&id=1&Itemid=2

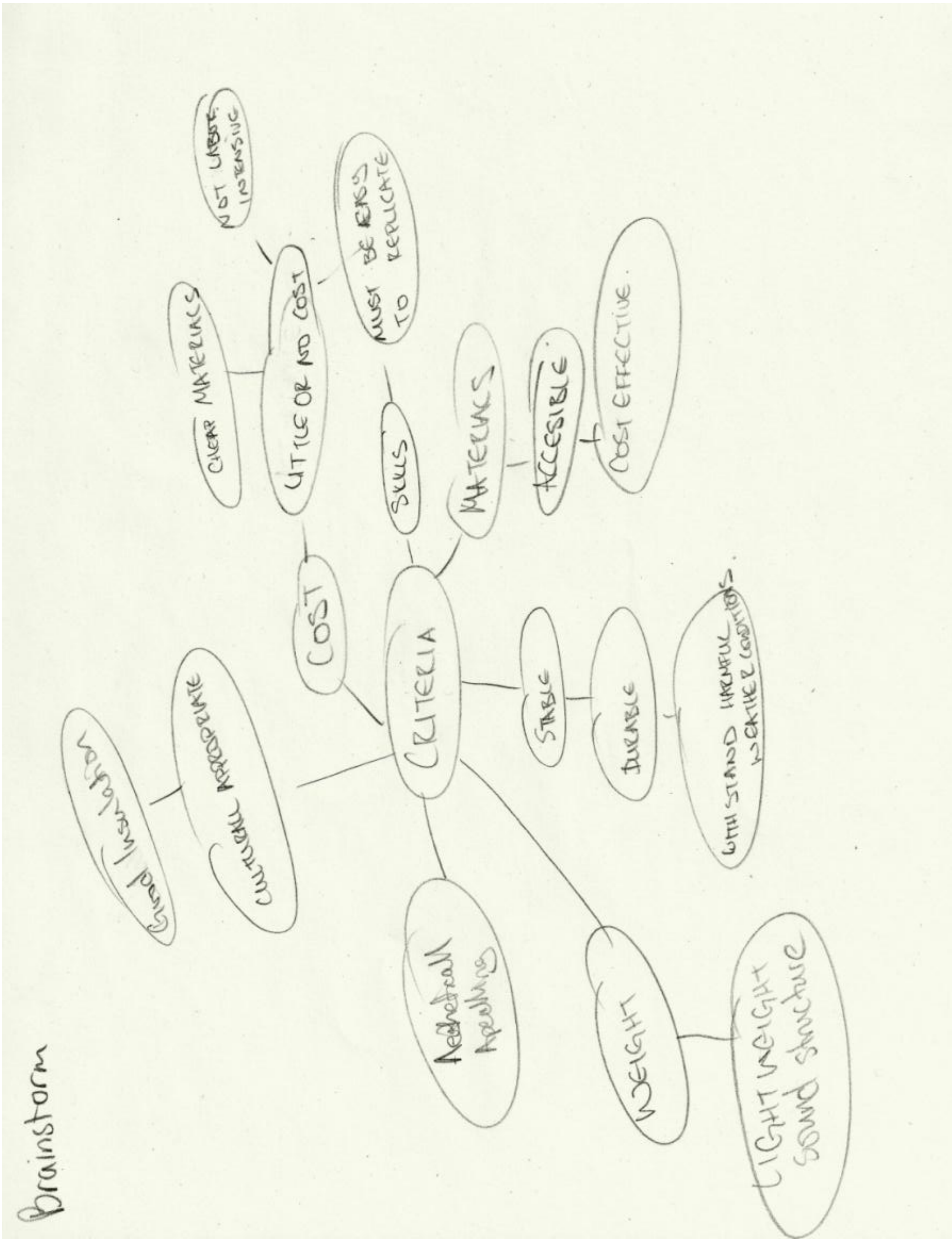
6.1.15. Design Build Live. (May 15, 2010). *Cob Comprehensive Workshop*. Retrieved from http://designbuildlive.org/

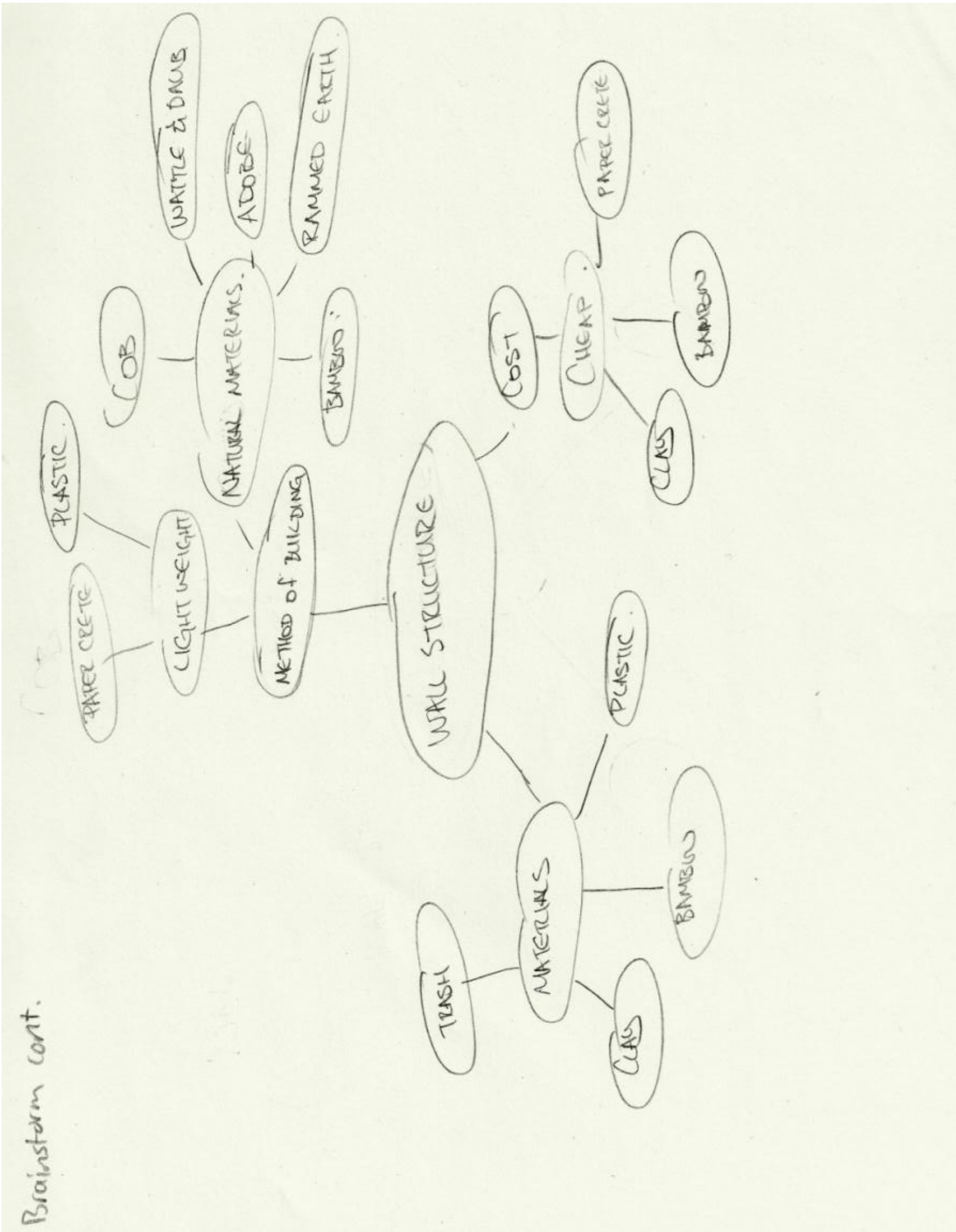
6.1.16. DeVries, S.K. (2002). "Bamboo Construction Technology for Housing in Bangladesh." Eindhoven University of Technology of the Netherlands. Eindhoven, Netherlands.

6.1.17. Graham, T. (2003). "Wattle and Daube: Craft, Conservation and Wiltshire Case study" University of Bath.Bath, England.

6.1.18. Sunshine,P.(2006). *Wattle and Daub*. Shire Publications Ltd. Princes Risborough, Buckingham Shire.
6.1.19. Johnson, P.J. (2009). "Evidence for a "Wattle and Daub" Model of the Cyst Wall of *Entamoeba."* <http://www.ncbi.nlm.nih.gov> (June 3, 2009).
6.1.20. California Integrated Waste Management Board.(2003). "Bamboo Flooring." <http://www.calrecycle.ca.gov/Publications/GreenBuilding.pdf>
6.1.21. British Recycled Products. Retrieved at Productshttp://www.britishrecycledproducts.co.uk/?Materials_and_Production:Recycled_Mixed_Plastics

## 2.1. Brainstorming Figure




Brainstorm cont.
WALL STRUCTURE
METHOD of BUILDING
LIGHT WEIGHT
PAPER CRETE
PLASTIC
NATURAL MATERIALS
COB
WATTLE & DAUB
ADOBE
RAMMED EARTH
BAMBOO
COST
CHEAP
PAPER CRETE
BAMBOO
CLAY
MATERIALS
PLASTIC
BAMBOO
CLAY
TRASH