One Size Does Not Fit All: Innovation in Emergency Housing with a Focus on Nepal 2015

by

Jamie L. Voros

Submitted to the Department of Architecture
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Abstract

Every year millions of people are displaced due to natural disasters and very primitive transitional shelters, or 't-shelters', exist to provide semi-permanent housing. Many t-shelter designs do not cater to all the needs of their inhabitants and are only functional in the short term, often leaving many people relying on t-shelters for housing in an unsafe and unsanitary environment. This thesis addresses the problem of people needing housing and of unsafe transitional housing by presenting a new design process and ultimately a t-shelter design specifically for the victims of the 2015 earthquakes in Nepal in the Kathmandu area. The process involves three key elements; identifying the specific needs of the displaced people, analyzing what materials and labor are available and ensuring that the shelter will be used as intended and therefore remain safe. The resulting shelter design harnesses the structural strength of the geodesic dome, the simplicity of reciprocal joinery and strong yet lightweight nature of bamboo. The effectiveness of the proposed new design process is demonstrated through checking the resulting shelter design meeting measurable outcomes like cost, structural integrity and skill level required to construct.

Thesis Supervisor: Caitlin Mueller
Title: Assistant Professor of Structural Design

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Lastly, I could not have done this with without my friends; I thank Scarlett Koller and Johannes Norheim for helping me build the scale model dome, with special thanks to Alana Papula and Filip Twarowski who stayed all day to see the prototype all the way through to completion.

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Chapter 1

Introduction

1.1 Motivation

In the spring of 2015, Nepal was struck by a sequence of earthquakes causing loss of lives, immense damage and leaving over two million people displaced [6, USAID, 2015]. Unfortunately, Nepal is not unique in experiencing such a large scale disaster; in 2010, many Haitian houses were shattered by earthquakes of similar magnitude, again leaving millions of people without access to proper housing [21, Britannica, 2016]. Right now, Europe is being rocked by waves of Syrian refugees seeking asylum in countries that do not necessarily have housing available [9, Amnesty International, 2016]. Ultimately, every year, millions of people are displaced due to unavoidable and unpredictable natural disasters or political unrest.

Transitional housing is a form of semi-permanent shelter typically provided in disaster or emergency stations to aid the recovery process. Typically coming in the form of a single room t-shelter, transitional housing acts as a stepping stone to bridge the gap between emergency housing, such as tents of tarps, and permanent housing. Transitional shelters are built with the hope that in the time the shelter lasts, permanent housing can be sourced.

While t-shelters function in practice, newer technologies have great scope to improve existing designs with each iteration. The concept of the evolving blueprint of the t-shelter is especially important because each disaster or emergency situation will have its own design constraints and different orders of priority. After a disaster, a given location will have different hazards, foundations, planned life span, budget and so on.

1.1.1 Goals

Given the necessity of rapidly constructible housing that is able to last from one to ten years, the goal of this thesis is to examine existing shelters and from that analysis present and test a new design process. This thesis aims to understand what makes some shelters so successful and how other shelters could better meet the needs of their inhabitants.

1.1.2 Research question

In what way is it possible to improve the current transitional shelter design process and optimize it to fit the requirements of a specific disaster situation? Calling upon design techniques from previous t-shelters, this thesis shall present a shelter design that caters specifically to the requirements of the victims of the Nepal 2015 earthquakes. Analysis of the design shall demonstrate how specificity in design results in a more effective shelter.

1.2 Thesis organization

This thesis is divided into five sections including this introduction; Literature review, Design framework, Design solution and Conclusion.

Literature review is a breif analysis of humanitarian aid projects and narrows down to analysis of t-shelters specifically. Design framework outlines the design process, the overarching method used to arrive at the resulting t-shelter that is presented in Design solution. The Design solution section goes on to analyze how well the presented design met the requirements laid out. The Conclusion offers a summary of where the design is successful and where it is not along with potential future work.

Chapter 2

Precedents and literature review

What is humanitarian aid? There are millions of people around the globe that would gladly welcome something that falls under the umbrella term of humanitarian aid. Expanding the theme of aid further out, are there other scenarios in which people provide and receive aid? What are they and why?

2.1 Who do we provide aid to and why?

Situations that require outside intervention occur where those giving the aid deem the people receiving the aid as unable to help themselves. Aid in a disaster situation, for example; the wake of hurricane Katrina, is typically sought after. Aid is provided when there are people willing to provide it to a certain group or population that they deem to be in need of it. It is difficult to find evidence of aid being given to those who are in 'greater need', in fact, it is difficult to find a pattern in the way aid is allocated at all. The inconsistency of aid allocation stems from people donating irregularly; sometimes because a charity's morals align with their own, or due to influence of others [24, Sanders and Tamma, 2015]. Whether or not aid via practical application is appropriate is case dependent, common themes among effective aid endeavors are a specific 'mission' or 'goal' that ultimately solves a problem. Overall, while aid is provided in a generally non-systematic manner, effectiveness can still be achieved through careful planning.

Typically, situations with housing shortage can be sorted into two different groups. One is a shock: for example, the aftermath of hurricane Katrina, or any natural disaster that destroys buildings or homes, will create a situation where aid in the form of housing is sent. The other is a pre-existing shortage of what is deemed adequate housing, felt in poorer parts of the country or world.

The Ford Foundation is a good example of a non-profit that provides asset building to reduce poverty; the mission statement argues that providing assets to those in the developing world can help increase prevalence of democracy, reduce poverty, and allow cooperation to flourish. I find this to be a very good example of why we choose to provide housing as a form of aid; there are immediate benefits derived from having proper housing and these go onto provide further benefits to the community as a whole. This is where housing has been used as a form of aid to actually have a positive impact on the underlying state of the economy. Thus I argue that one of the secondary reasons that one might choose to send aid in the form of housing (or asset building in this case) is to change people's lives and empower them. Aid in the form of housing is also provided in post disaster situations, such as the earthquake in Haiti in 2010. In a post disaster situation, along with food and water, shelter is a basic human need and lack thereof can cause further distress. Overall, outside a disaster situation aid is provided in the form of housing or shelter because it tends to be a more permanent step towards improving an economy. In a disaster situation shelter is provided to offset the distress people feel from being displaced.

2.2 How should we decide who to provide aid to?

What should factor in to allocation of aid? Should we factor in who will find our skills the most useful or helpful, or should we help those who need it most? How do we define "need it most" and our usefulness? In *Aid Effectiveness and Selectivity*, McGillivary notes that aid allocation is something that can influence its effectiveness[19, McGillivary, 2003]. Therefore, whom aid is given to may need to be taken into account when designing an aid package. McGillivary touches on the ethical and moral implications of making a conscious decision about whom you are going to provide aid to [19, Ibid]. Should one aim to provide aid to the people for whom it will be most effective, or to those that need it most? This is going to be a moral question that may skew the research stage. McGillivary identifies several key directions that aid can push a country or community in or have an impact on aid effectiveness; trade shocks and aid effectiveness are correlated because trade shocks or quickly changing commodity prices can drastically affect growth [19, Ibid]. Structural vulnerability will influence the effectiveness of aid in that the magnitude of the aftermath of a trade or climactic shock is a function of the structural vulnerability. Political instability also correlates negatively with aid effectiveness [19, Ibid]. The negative effect of political instability is due to likely higher levels of corruption in more politically unstable environments; which reduces the amount of an aid package that is actually used for its intended purpose. Democracy and aid follow a similarly expected relationship; the higher the degree of democracy, the higher the effectiveness of aid. The existence (or non existence) of transmission mechanisms will influence the impact of aid; aid can affect growth directly, but can also influence investments, supply chain, government policy and so on. Lastly, there are diminishing returns on aid provided; ultimately the relationship between amount of aid supplied and economic growth observed is not possible to define without holding many other factors constant (such as political instability, culture or current state of economy).

2.3 Measuring aid effectiveness

There are multiple metrics by which to measure the performance of an aid package, such as cost, number of people helped, speed of delivery, cost per person helped. Therefore there are many ways to measure its effectiveness. Even following the same disaster, aid packages can be effective in targeting different problems, such as housing or hygiene. Thus, in order to compare or design an aid package that aims to be more effective, it is necessary to hone in on the aims of the aid package. The needs that aid packages are catering to should be similar if they are to be compared: for example, the need for quickly erectable, long-standing shelter following either and earthquake or hurricane tends to be fairly similar. From these same driving requirements, or aims, of an aid package, one could then make some sort of comparison using quantitative measures like cost, life time, build time and so on. It is important to note that by setting design requirements before beginning to design the air package, it becomes far easier to evaluate its performance. Nevertheless, in the research phase, it is still possible to set requirements for and aid package after it has been implemented, given the main goals of the package and then evaluate the package performance against them. For example: after the Haiti 2010 earthquakes, factors like response time, infrastructure and transport should factor in to requirements to evaluate an aid package against when measuring its effectiveness.

2.4 Shelter as aid and the t-shelter

Going back to the case of displaced people, in 2015 alone refugees, victims of natural disaster and asylum seekers made up over 25 million displaced people around the globe. Given our inability to predict when natural disasters will occur (within sufficient time) and political instability in many parts of the world, the need for rapidly constructible transitional housing is not going to disappear in the near future. Figure 2-1 shows displaced people and where they come from for 2015 alone. Right now, natural disasters are the main cause of displaced people and are typically in third world countries.

Following the earthquake in Haiti in 2010, immediate housing was part of the transitional shelter initiative, which aims to provide post disaster housing. Transitional shelters, or t-shelters, are all fast to build and temporary; build times are of only a few days and the t-shelters can last between 3 and 10 years [11, Beunza and Eresta, 2011]. The Haitian transitional shelters, or t-shelters, were all designed to be built incredibly quickly, a matter of days, but the amount of time such shelters remain standing varied widely. The t-shelters were widely constructed following the earthquake and even within this family of shelters we see them becoming much longer

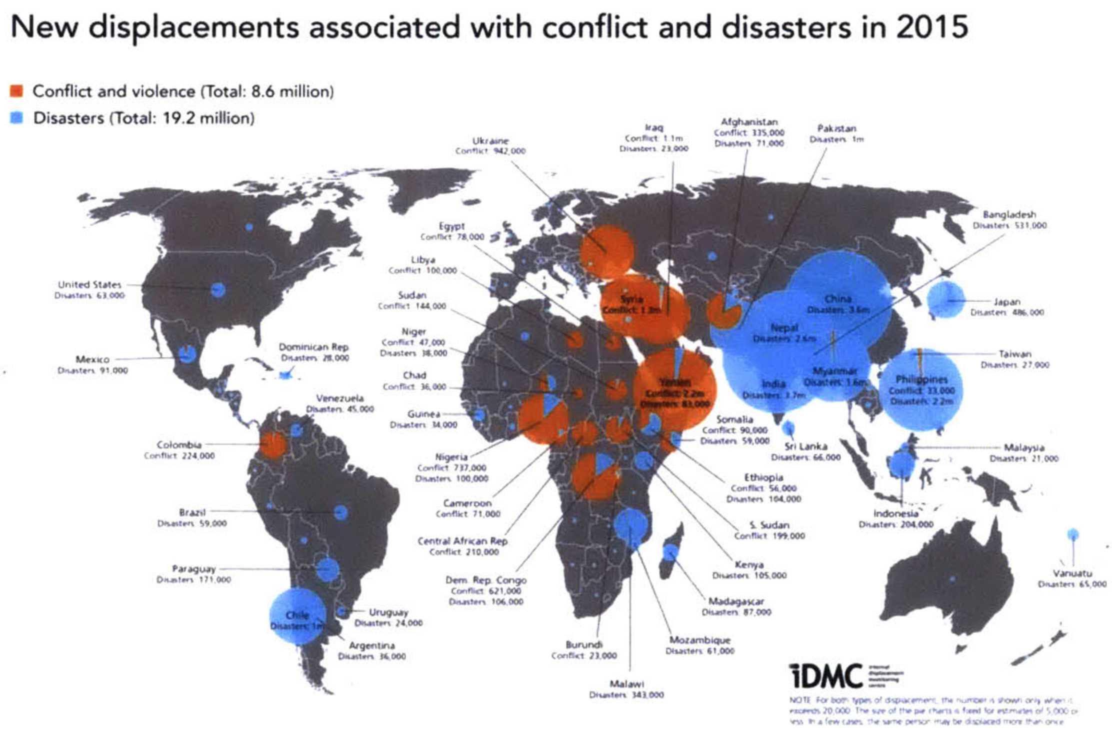


Figure 2-1: Displaced people by country and disaster type in 2015 [8, IDMC, 2016].

Figure 2-2: T-shelters following the 2010 Haiti earthquakes. Left [3, ARUP, 2012]. Right [25, Vanderwillik, 2012].

lasting, demonstrating a change in aid mission goals. They were initially designed to be transitional but some alterations were built to last up to ten years [5, The Red Cross, 2013].

Transitional shelters were also used following Tropical Storm Washi in the Philip pines in December 2011. The shelter design was function driven; Catholic Relief Services or CRS worked with local architects and engineers to design a product that would, at a low cost, meet the driving requirements for shelter following Washi, see figure 2-3. Unlike the Red Cross article, the CRS article goes further into integrating other resources like water and hygiene products. The CRS article also mentions that the Philipino shelters were effective not just because of their design, but because of the timeliness of the response and low cost, partially attributed to the ability to get and transport materials and financial resources.

2.5 Potential and limitation of current designs

As per The Red Cross' *Post Disaster Shelter: 10 Designs*, many t-shelters exist to varying degrees of success; the limitations addressed in this thesis are those pertaining to privacy, security, cultural fit and hygiene in order to propose a design method and thus design that is ultimately a better fit for the people living in it.

Many of the t-shelters in The Red Cross' two publications, *Post Disaster Shelter:*

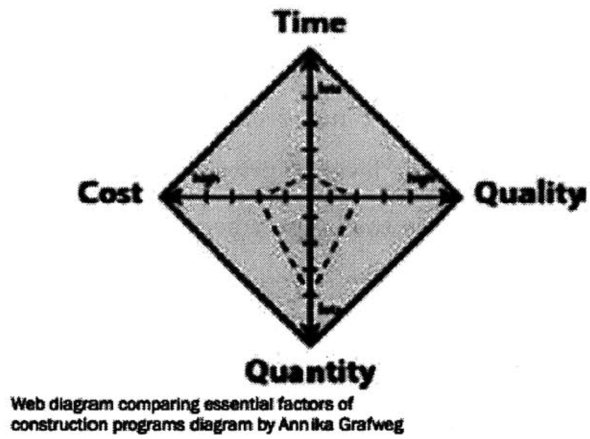


Figure 2-3: Web diagram of needs for a t-shelter in the Philippines following Washi [16, Hirano, 2012].

10 Designs and *Transitional Shelters 8 Designs* follow a simple box and hat design. Despite the striking similarities in general form and floor area (all hovering around $25m^2$), figure 2-4 shows considerable span over lifetime and cost.

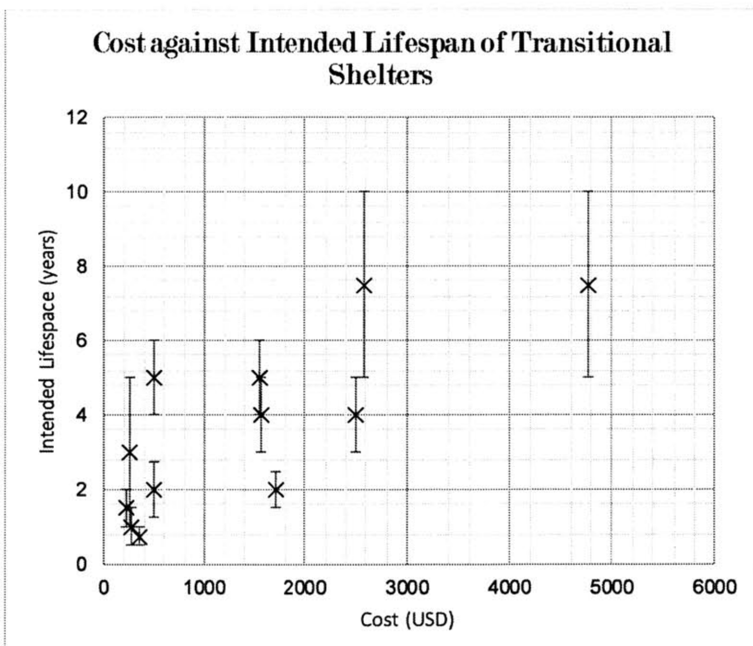


Figure 2-4: Graph to show cost against lifespan of t-shelters [5, The Red Cross, 2015].

Furthermore, none of the shelters have proper internal walls or rooms; although at $25m^2$, most of The Red Cross' shelters are large enough, they do not cater to privacy as we know it in the West. Of course, not every culture will have the same views on privacy, multiple rooms and some level of privacy would be a better fit for some families or cultures. Allowing people to choose whether or not they would like rooms would allow any t-shelter with the option of rooms to cater to people who want them and those that do not. The ability to choose the internal layout would not only allow personalization of a shelter, but it would also let the space be used most effectively by catering more closely to the needs of the people using the shelter. Naturally most of these questions about privacy require the people living in the shelter to be present while it is being built; where consulting with the people for whom the shelter is being built is not possible, designing a culturally appropriate internal layout may be beneficial.

The Red Cross publications note, "additional features such as lockable doors may be required," but, unfortunately, none of the shelters actually address the problem with security and personal safety. Ikea, however, has designed a shelter for refugees that features a locking door and the resulting shelter is considered not only safe, but allows the refugees to feel more dignified [22, Peters, 2015]. Thus Ikea has demonstrated the success of locking doors increasing user happiness for Syrian refugees.

Similar to locking doors, a handful of shelters have a separate bathroom, but most do not [5, The Red Cross, 2015]. Lack of a bathroom is not necessarily a problem, depending on the location of the t-shelter, bathroom and human waste options may exist in the vicinity, for example a cluster of t-shelters may have a set of communal bathrooms nearby. In cases where such sanitation is not available and given the cost of a basic composting toilet, adding a bathroom onto an existing shelter.

On the other hand, designs like Shigeru Ban's shelter for Nepal, shown in figure 2-5, are successful. Shigeru Ban's shelter has walls inside and makes use of the earthquake rubble as part of its building process [10, Shigeru Ban, 2015]. Among many others, one reason why there is such disparity in shelter success is the fact that many shelters are similar but disaster situations are not. For example, both New

Zealand and Haiti were struck by earthquakes in 2011 and 2010 respectively, however the people displaced in New Zealand had very different needs and wants from those in Haiti. People in both countries were left without housing, however that housing had to cater to different climates and had a different expected lifespan. New Zealand was far better prepared and able to handle the disaster and transitional housing was not needed very long whereas in Haiti, there are people still living in transitional shelters.

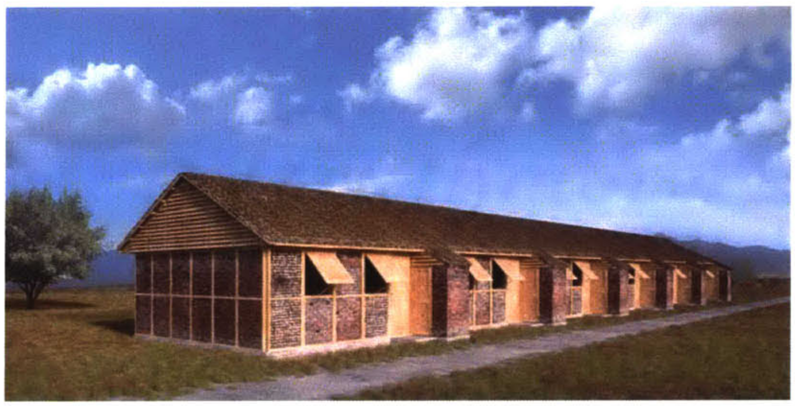


Figure 2-5: Shigeru Ban's Shelter for Nepal [10, Ibid].

Ultimately, different disasters having different requirements feeds back into the original research question: In what way is it possible to improve the current transitional shelter design process and optimize it to fit the requirements of a specific disaster situation?

Chapter 3

Design framework

To give a brief refresher, the site is the Kathmandu area in Nepal where, in spring of 2015, over two million people lost their shelter to a string of high magnitude earthquakes [6, USAID, 2015]. The epicentres of two major quakes were just to the north of Kathmandu, as shown in figure 3-1.

3.1 Overview

The method follows a requirements based system in order to fully address the problem of designing housing for a specific purpose. Requirements are drawn up in order to both better understand the problem being solved and also to serve as a method of measuring how successfully the design solves the problem afterwards. The requirements can be extended into a rating system for the successfulness of the shelter and potentially other shelters.

3.2 Data collection and analysis

3.2.1 Existing t-shelters

There are huge numbers of existing t-shelter designs, including many for the same location [5, The Red Cross, 2013]. The intended lifespans of designs varied widely,

Figure 3-1: Map to show major earthquake locations in Nepal [6, USAID, 2015].

as did cost and location. Floor area, however, was fairly consistent across almost all designs, hovering around $25m^2$ [5, The Red Cross, 2013].

The lack of correlation between cost is due to different availability of materials and probably also because of different funding levels; not all t-shelters are designed and implemented by the same organization and not every t-shelter project will have access to the same funds and resources.

Putting cost into a requirement for a theoretical shelter proved difficult because cost does not depend on the disaster situation, but depends on the funding available for that particular shelter initiative. With this in mind, the requirement set for cost was intended as an absolute upper bound based on the cost of the more expensive existing shelters.

3.2.2 Climate and weather

Rainfall and temperature data from Nepal's Ministry of Environment is from 2000-2010. The minimum temperature near the Kathmandu airport weather station was

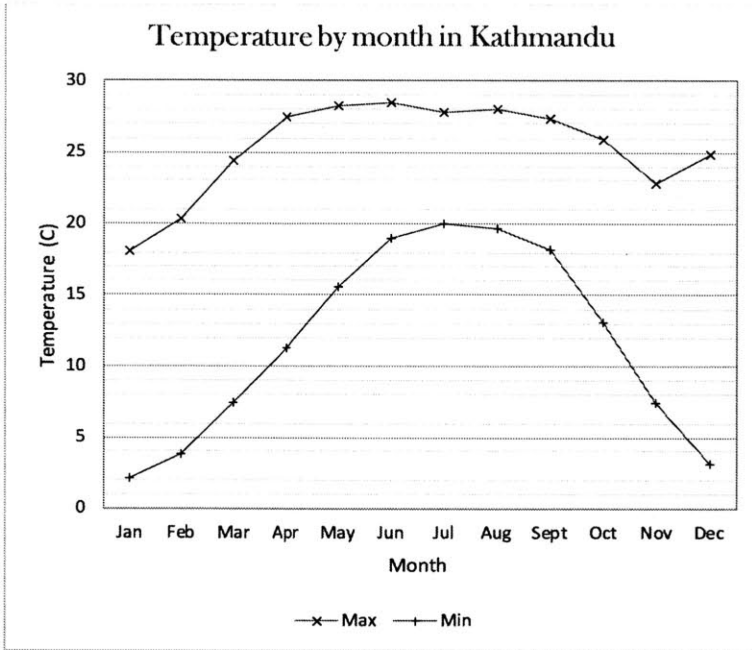


Figure 3-2: Graph to show temperatures in Kathmandu [17, Karki, 2010].

2.1°C, happening in January, and the highest was 28.5°C in June [17, Karki, 2010]. They give upper and lower bounds for the temperatures that a t-shelter needs to be able to insulate from.

The rainfall does not give a numeric metric, but indicates that there is a monsoon season. Given that every month includes rainy days on a regular basis, especially the warmer summer months, a t-shelter for Kathmandu must be completely rainproof as soon as possible [17, Karki, 2010]. Figures 3-2, 3-3 and 3-4 give an idea of how much rain Kathmandu experiences and how temperature extremities change over the year. Figure 3-4 fortifies the argument for the shelter being immediately waterproof. Figures 3-3 and 3-2 indicate that the maximum and minimum temperatures are only experienced in one month per year.

3.2.3 Interviews

Three Nepalese students affiliated with MIT were interviewed in order to gain a better understanding of cultural expectations of housing and what would be appropriate

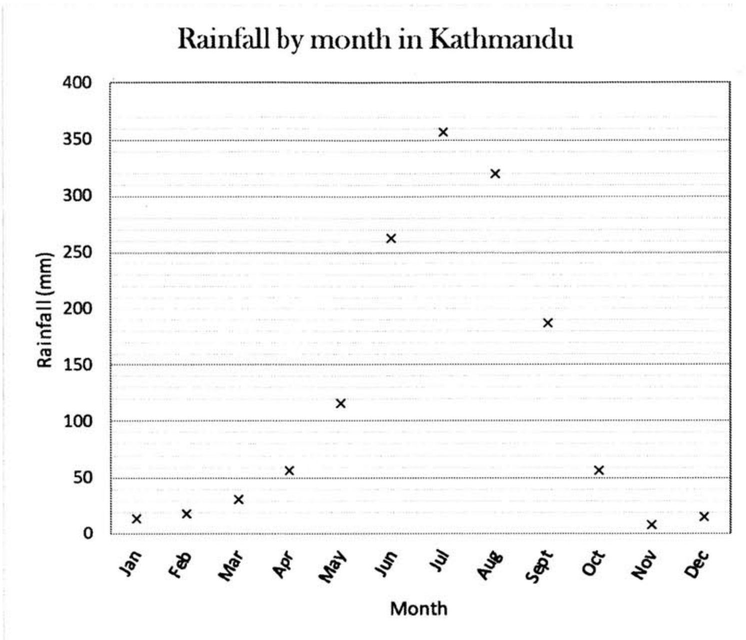


Figure 3-3: Graph to show *mm* of rainfall in Kathmandu [17, Karki, 2010].

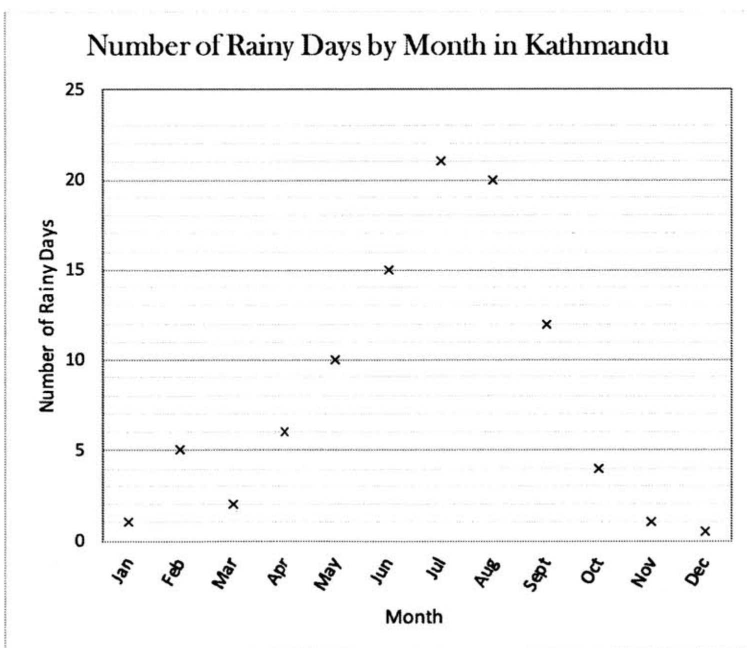


Figure 3-4: Graph to show rainy days Kathmandu [17, Karki, 2010].

and accepted as a form of housing. Each interview consisted of a series of questions pertaining to family structure, privacy, hygiene and availability of electricity.

Full interview notes can be found in the appendix, the key cultural aspects taken away from the interviews are:

- nuclear family structure
    - parents and children living together
    - after marriage girls go to husband's family
- whole family sharing one sleeping space acceptable
- parents sharing a sleeping space and the children sharing another acceptable
- living space and kitchen space often combined
- guests go anywhere in house
- cooking in main living space
- kerosene or gas stove

These main pieces of information that influence house design were taken into account when drawing up design requirements.

3.3 Design requirements

Resulting design requirements were made based on data collection. All requirements fall under five main design goals:

- House 5 Displaced People
- Cost no more than 5000 USD
- Constructible in 10 days
- Last 5 years

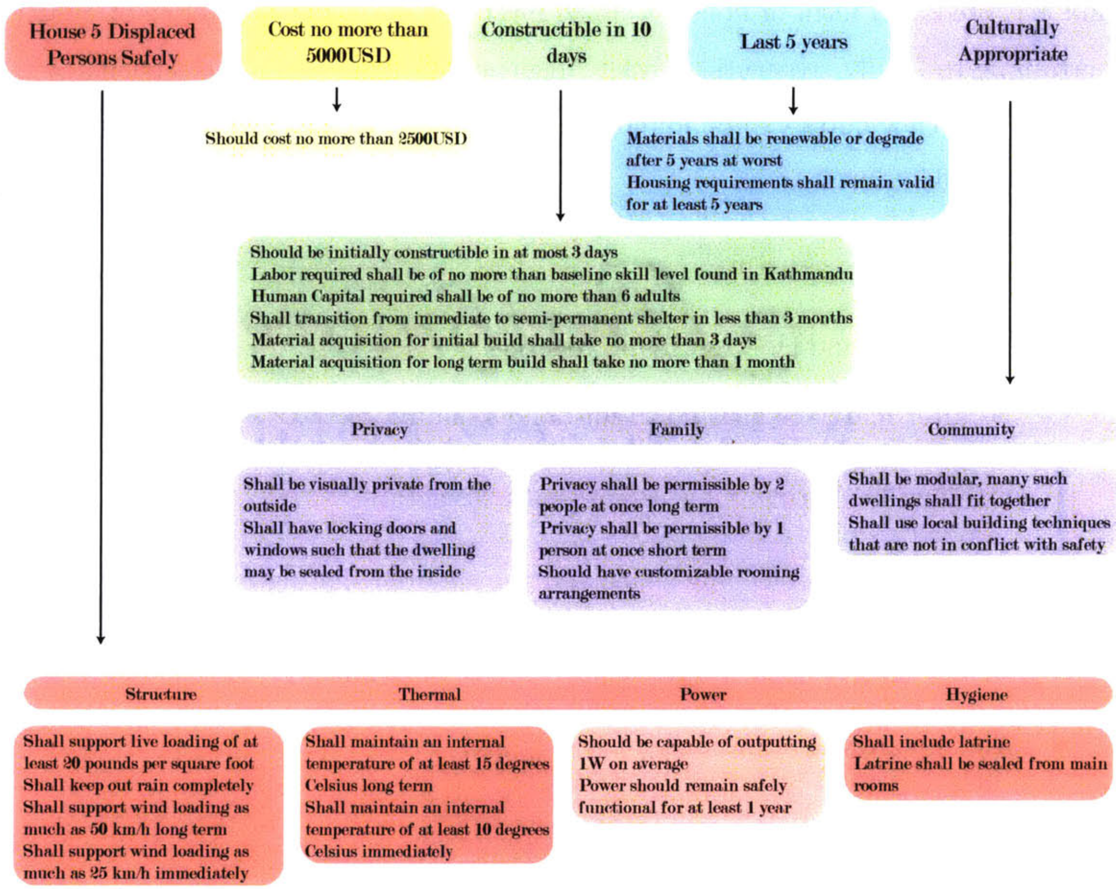


Figure 3-5: Graphical representation of design requirements.

- Culturally Appropriate

Figure 3-5 is visual representation of how requirements stem down from each other. Note that some requirements use 'should' instead of 'shall'; these requirements are soft requirements, the shelter does not necessarily need to meet them, but it would be beneficial.

Chapter 4

Design solution

The design presented hits most of the design requirements, a major difference is that instead of having a short term and semi-permanent state, the design goes from immediate to permanent.

4.1 Overview

The base structure of the shelter is an altered second order geodesic dome; a dome made with many straight elements that approximates a half sphere. This dome has been altered to use elements of only one length to accelerate material acquisition and fabrication and to include a protruding doorway and latrine. Materials used are local and renewable except for the waterproofing sheet and lashing.

Unfortunately, the power requirements (all of which were soft) were not met because of difficulty with installing a solar panel that would be used safely. A solar array or panel outputs a varying voltage depending on sunlight and cannot just be hooked up to an appliance; in order to remain safe a solar array or panel should charge a power bank (set of batteries). Adding a solar panel safely is definitely a way to improve the design, but was unfortunately, not possible to fully develop in the timeframe of this thesis.

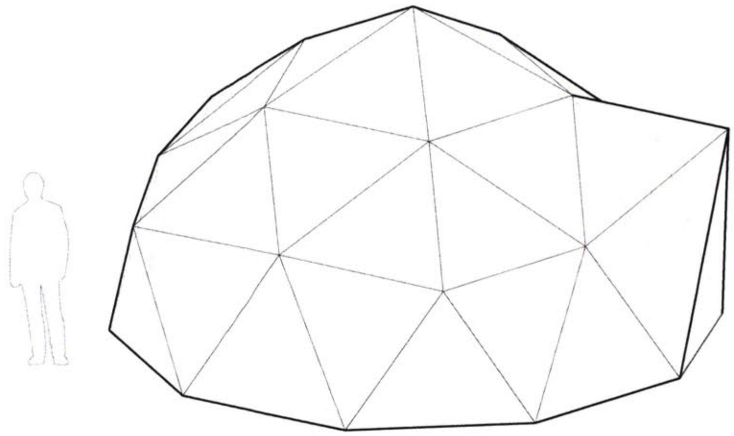


Figure 4-1: Design solution overview.

Figure 4-2: Left: Example of a reciprocal joint [18, Lewandowski, 2015]. Center: Geodesic dome home construction in Israel [15, Dodinval, 2015]. Right: Mud and straw houses in Sudan [20, Mysliborski, 2006].

4.2 Inspiration

Geodesic domes have been around since the early 1900s and were popularized in the United States by Buckminster Fuller for their structural integrity, thermal efficiency and resistance to wind loading [14, Davis, 2004]. Geodesic domes have been used in simplistic housing before, figure 4-2 is an example from an Israeli kibbutz.

Similarly, reciprocal joinery, also shown in figure 4-2, has been used before. It is very applicable to breaking down the joint complexity in the frame of a geodesic dome with five or six beams coming together at once.

Lastly, using mud and straw in houses, shown in figure 4-2 is an incredibly old building technique. Mud and straw are especially applicable in this scenario for the

Frame	Waterproofing	Insulation	Foundation
65 1.85m Bamboo poles Elasticated chord Waxed lashing chord	Waterproof tarpaulin Waxed chord	Mud Straw	Chicken wire Rubble

Table 4.1: Table to show materials and which part of construction they are used for.

non planarity of the resulting insulation material and thus the ease of applying it to the curved surface of a dome.

4.3 Construction

4.3.1 Materials and labor

The design features four main parts, for each part a breakdown of materials is listed in table 4.1. The labor required is that of four able bodied adults. In the short term, construction is expected to take three days, with flexibility of build time in the long term dependant on how much the residents want to add on to the shelter in the way of insulation, locking doors, windows or internal walls.

4.3.2 Frame

The frame is to be constructed of Guadua bamboo, a thick growing construction grade bamboo. Often used in China as a construction material, bamboo is readily available either in Nepal or for import from China. Bamboo is advantageous as a building material in in an earthquake prone area because of its flexibility. A shelter with a bamboo frame is able to withstand ground movements because the bamboo beams themselves are able to flex and thus absorb some of the shock. Furthermore, bamboo is lightweight yet has high yield and compressive strengths.

The skeleton of the shelter is an altered geodesic dome with reciprocal joints, the reciprocal joints mean that custom joints are not needed and that lashing can be

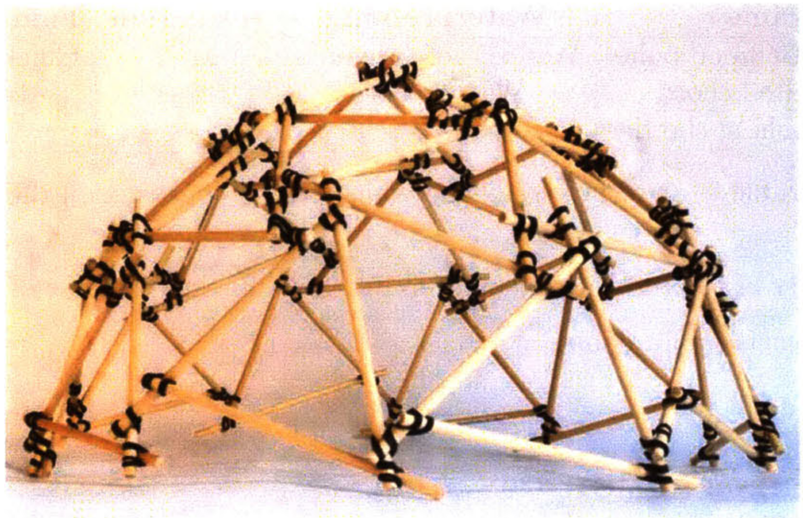


Figure 4-3: Photo of 1:12 scale model.

used. The 1 : 12 scale model in figure 4-4 shows how all the elements fit together in the base dome structure.

Using Karamba, a structural analysis tool for Grasshopper, element utility under $40lbs.sq.ft.^{-1}$ foot of live loading was measured [4, Karamba]. The algorithmic nature of Grasshopper enabled different alterations of the dome to be analyzed in quick succession. Figure 4-3 shows several alterations of the original geodesic dome under $40lbssq.ft.^{-1}$. As shown, even with very pronounced augmentations and element distortions, the maximum utility is still under 30%.

4.3.3 Foundation

The foundation uses gabions; large blocks made up of rubble netted in chicken wire. Figure 4-5 shows an assembly of gabions and figure 4-6 shows how the gabions interface with the bamboo frame and waterproof sheeting that goes over the frame. Note that the bamboo frame and waterproof sheeting are also tied into the netting, which is not shown in figure 4-6.

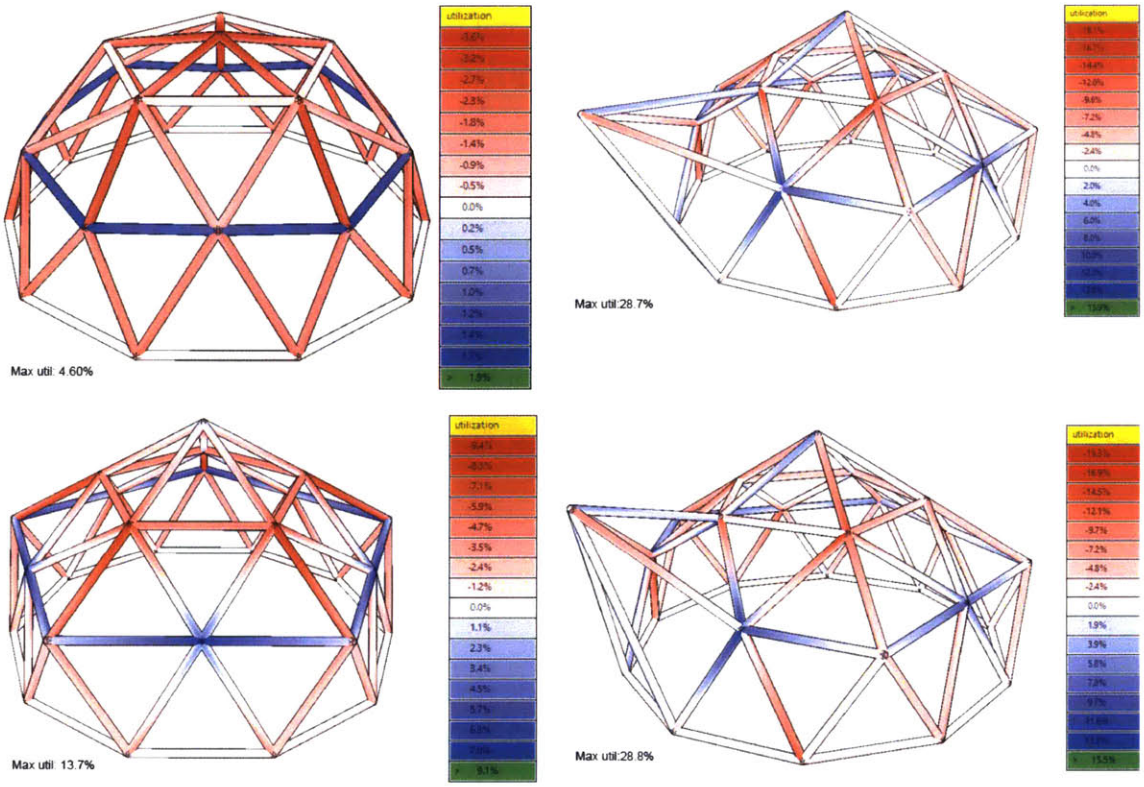


Figure 4-4: Structural analysis of different dome alterations.

Figure 4-5: Photo to show gabions [7, Nitin Wirenetting, 2015].

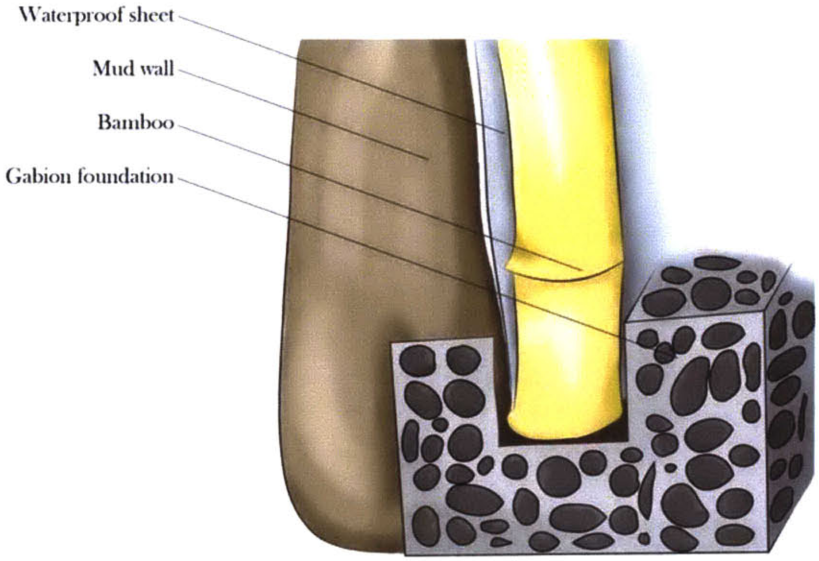


Figure 4-6: Diagram to show how bamboo and waterproof sheeting fit into gabions.

4.3.4 Waterproofing

A waterproof sheeting is to be placed over the bamboo frame as shown in figure 4-7. The waterproof sheeting may come as one or multiple tarpaulins. Using multiple tarpaulins is not a problem as they can be applied from the bottom up, with overlap, to ensure a waterproof interior.

The waterproof sheeting is intended to be the final part of the necessary short term construction. Although with low insulation, the translucent nature of the tarpaulin material will allow the house to act like a greenhouse, taking in energy from the sun, but reducing inside-outside air exchange and thus retaining the heat energy. If there is time, straw bales can be built up around the structure to add insulation.

4.3.5 Insulation

Immediate insulation comes from the waterproof sheeting and potentially also from bales of hay built up around the frame in preparation for mud slathering.

In the long term, the maximum temperature difference is expected to be: $\Delta T = 15 - 2.7 = 12.3°C$.

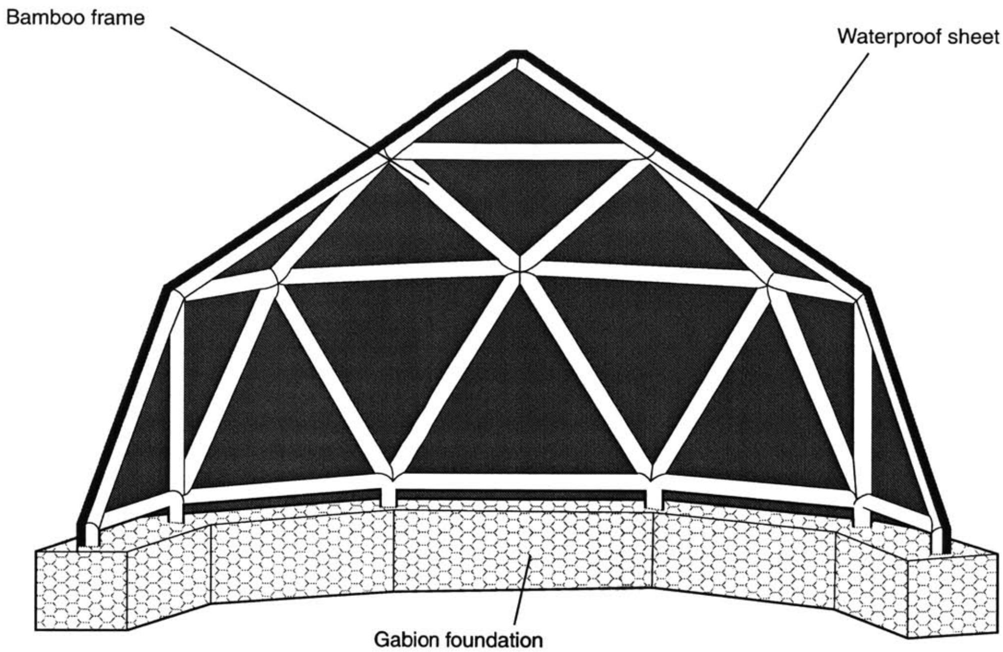


Figure 4-7: Waterproof sheeting **over** bamboo frame.

Based on a $2000kcal = 8,372,000J$ diet, each person is expected to output:

$$8,372,000Jday^{-1} = \frac{8,372,000J}{24 \cdot 60 \cdot 60} = 96.8W \approx 100W$$

for a total of $400W$ with 4 people inside the house.

The wall surface area of the house is made up of many equilateral triangles, each with side length $1.85m$. Side length $1.85m$ gives triangle area of $1.48m^2$; there are 40 such triangles, giving a total wall surface area of approximately $59.2m^2$ after accounting for augmentations. The floor area is a decagon of side length $1.85m$, giving floor area of $27.8m^2$. Thus the dome has total surface area of approximately $87.8m^2$.

$$\Delta T = R\dot{Q}_A$$

$$12.3°C = R\frac{400W}{87.8m^2}$$

$$R = 2.70m^2KW^{-1}$$

$2.70m^2KW^{-1} = 15.5ft.^2h^\circ FBtu^{-1}$; with straw bales at $1.5ft.^2h^\circ FBtu^{-1}$ per square inch stacked, 10 inches of straw bales are needed to be stacked around the outside of the shelter [13, Commins and Christian, 1998].

4.3.6 Hygiene

A basic composting toilet is included in the design, shown in figure 4-8; the composting toilet need only be a pair of plastic buckets with sawdust or straw and also a 'tap'. Figure 4-8 shows a simple bucket with a tap that can be filled with clean water and then used to wash hands after toilet use. Using a composting toilet means that flushing and running water are not necessary and it has no power consumption. Furthermore, a composting toilet is able to take other, natural household waste, such as kitchen waste [12, Solomon et al., 1998].

Separation of liquid and solid waste reduces odor and reduces risk of solid waste taking on too much water, which is problematic and detrimental to the functionality of a composting toilet [23, Del Porto, 2000]. The latrine must also have some ventilation in order to function properly, meaning that a gap is necessary in the waterproof sheeting [23, Del Porto, 2000]. Figure 4-9 shows a method of layering the waterproof sheeting in such a way that there is a small gap allowing some airflow, but not internal rainfall.

Lastly, the latrine shall be sealed from the main living space with the use of an internal wall. In the short term, the internal wall will be a locally sourced fabric, which can be tied and hung from many points along the bamboo frame.

4.3.7 Plan

The plan retains the original decagonal shape of the geodesic dome's footprint. The front door is elongated in order to more easily house a door. The base plan includes three rooms, shown in figure 4-10. The internal walls allow the design to cater to the privacy requirements. As with the latrine, in the short term, the rooms are separated

Figure 4-8: Left: Example bucket style composting toilet [2, Quake Kare, 2016]. Right: Example bucket tap [1, Govdhan, 2014].

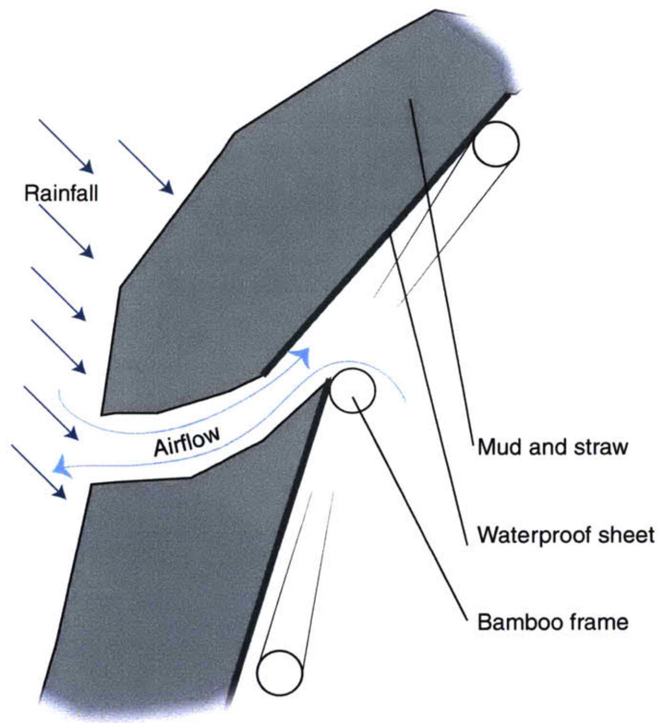


Figure 4-9: Diagram to show downwards pointing ventilation hole for latrine.

by locally sourced fabric hung from the bamboo frame. Owing to the symmetry of the geodesic dome, the walls can easily be modified to fit the needs of each individual family.

In the long term, internal walls can be built up with mud and straw; the only drawback being the reduced floor space from having walls with non-zero thickness.

The design does not currently feature windows; light is let in through the translucent waterproof tarpaulin. Translucent panes can be kept in the final shelter by not covering the entire dome surface when adding the mud and straw walls. Figure 4-10 gives an example of a break in the mud and straw insulation in order to allow sunlight through the translucent sheet.

4.3.8 Assembly

The bamboo frame is assembled first using elastic to secure the joints, as shown in figure 4-12. The use of elastic means that join locations and angles do not need to

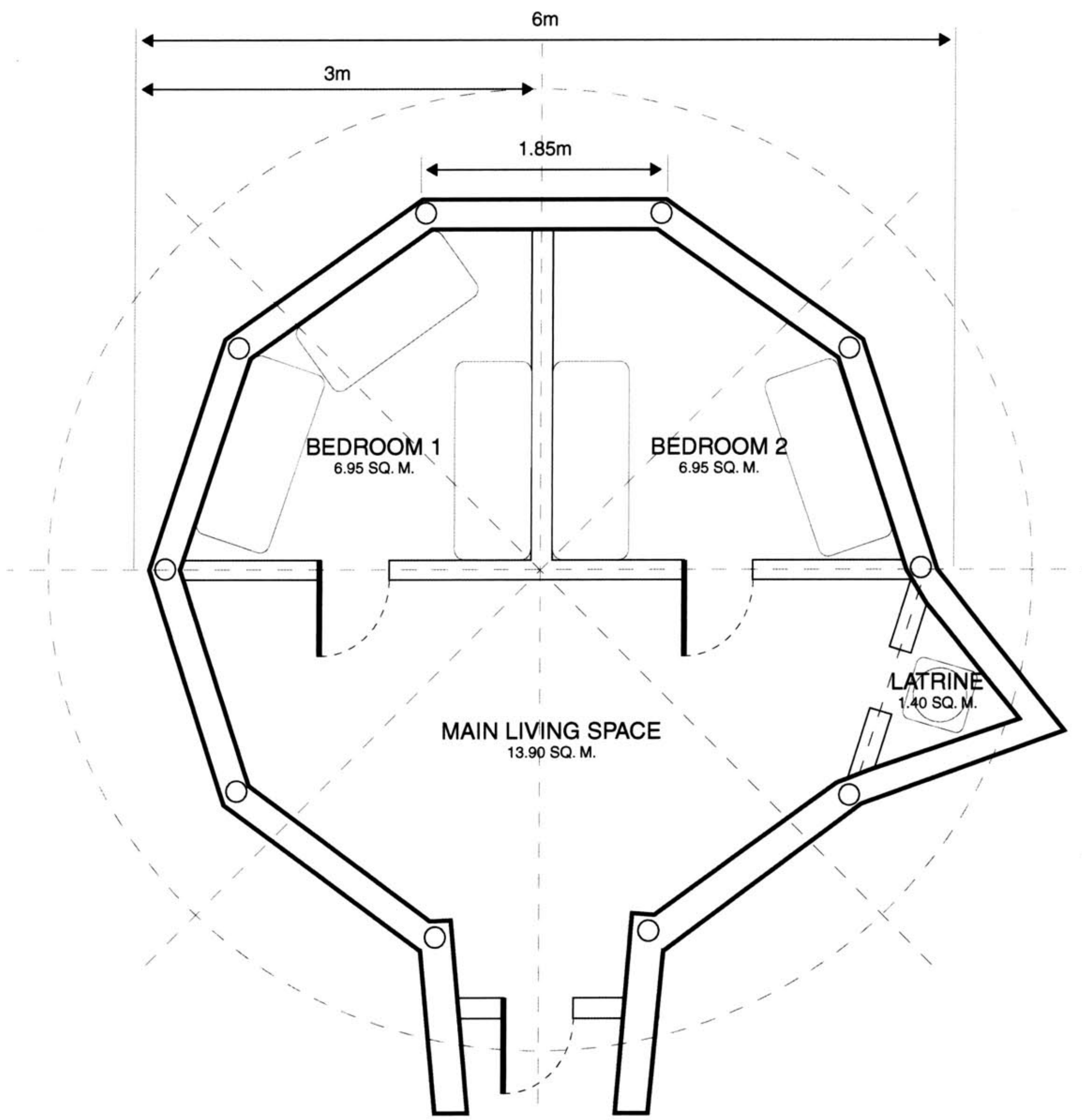


Figure 4-10: Base dome plan including latrine and doorway.

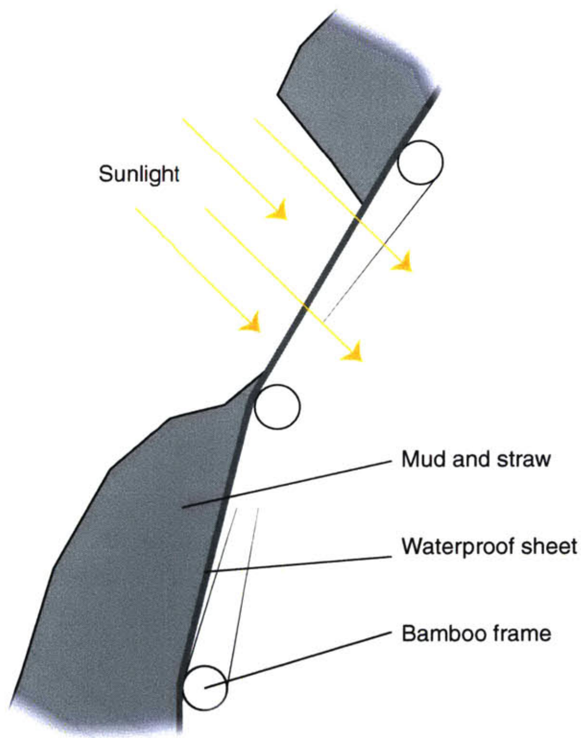


Figure 4-11: Diagram to show coverage to allow sunlight in.

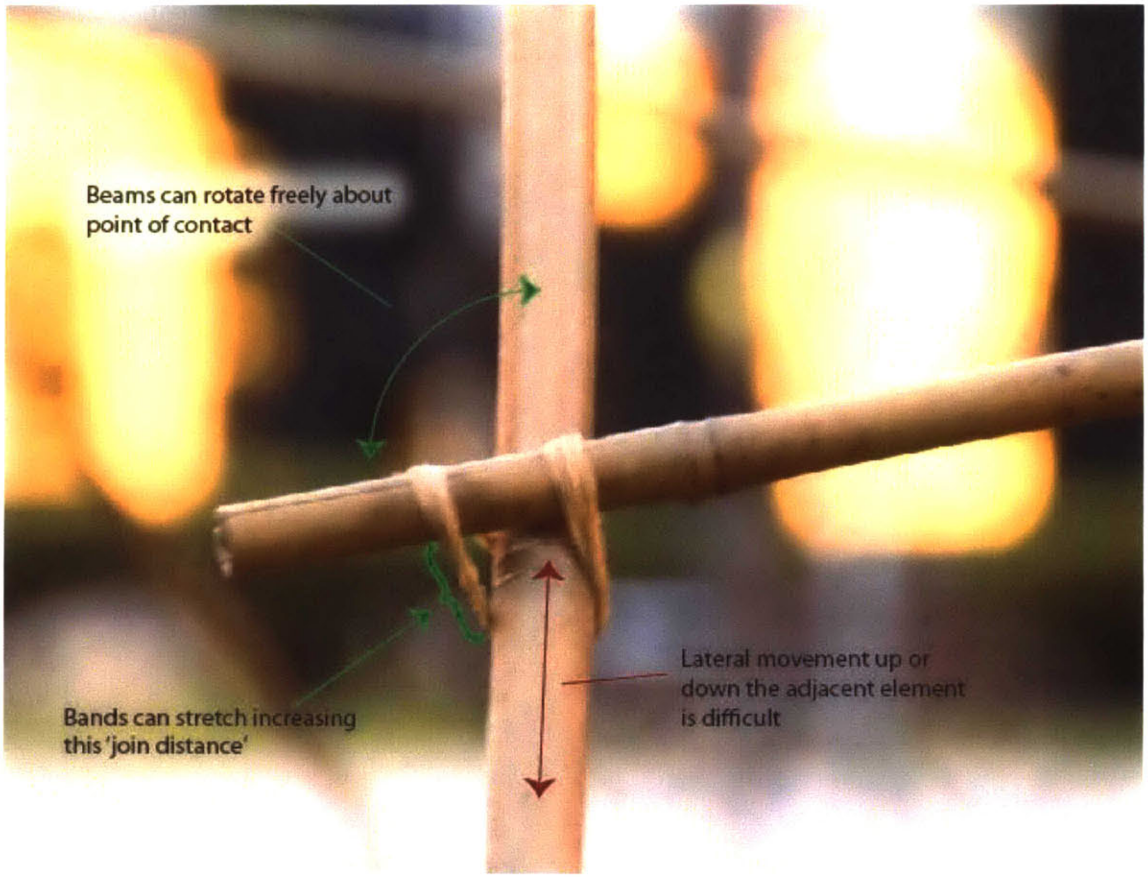


Figure 4-12: Photo to show a two beam joint.

be exact because the elastic is so forgiving and allows a join to be manipulated after joining. The rubber content means that the two elements will not move along each other unless the rubber is taken off the beam and moved. However, the rubber does allow the join angle and distance to change freely. Not requiring precision reduces the amount of tools and skill level of labor, it also decreases production time.

The frame is comprised of five identical pentagonal parts, shown in figure 4-13, and one irregular part for the latrine. Each pentagonal part is made up of ten beams of the same, $1.85m$, length.

The pentagonal pieces are fully constructed and then come together to form the dome. The join between any pair of pentagonal pieces is identical, one such join is shown in figure 4-14.

The frame assembly is finished with proper lashing chord to secure all the joints

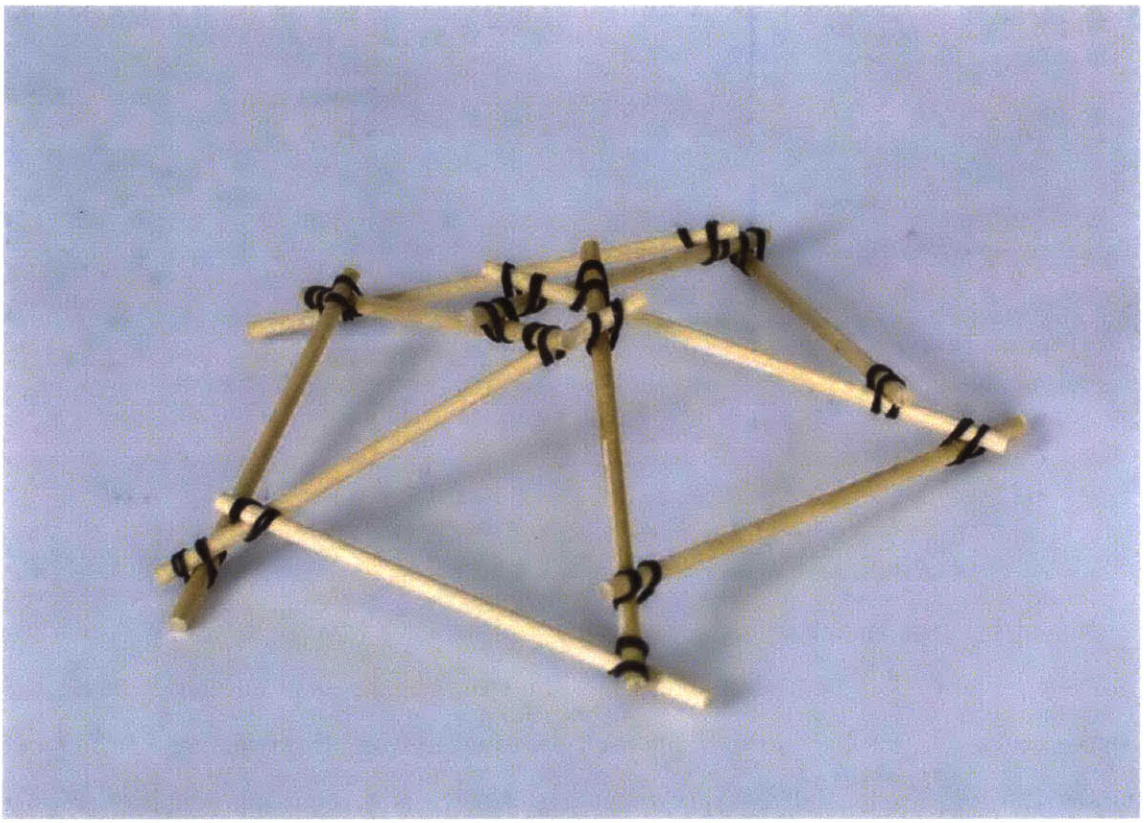


Figure 4-13: Photo of 1:12 model to show single pentagonal part.

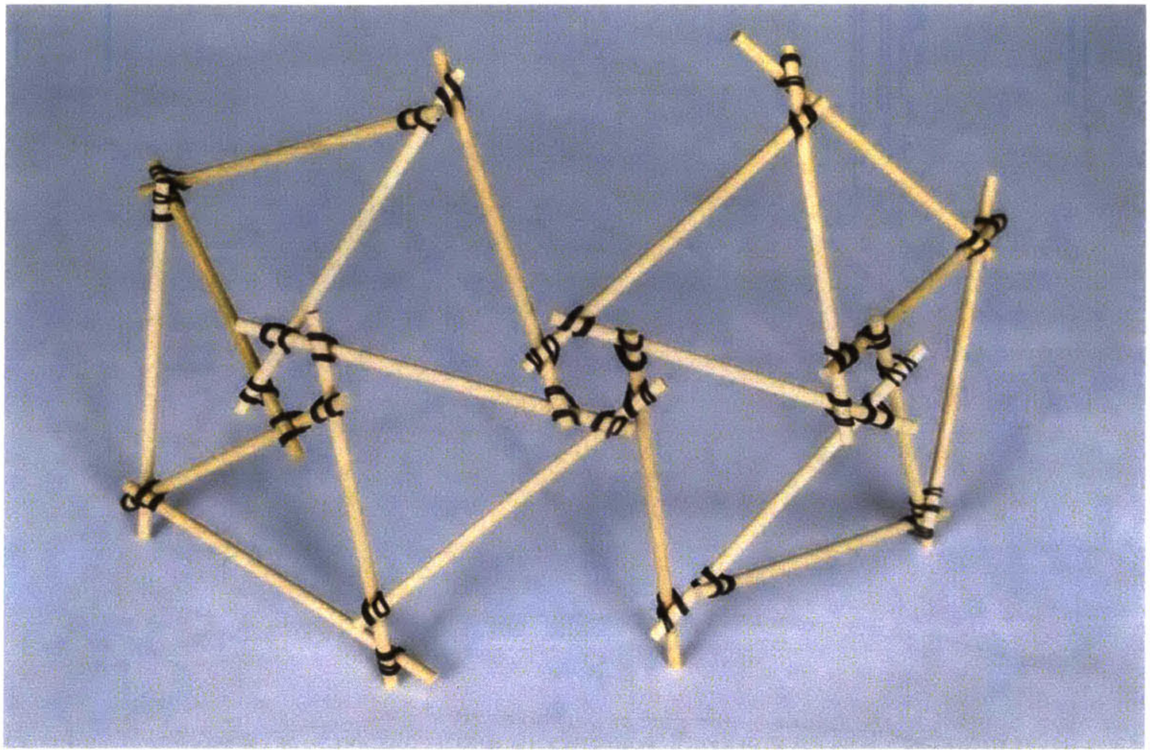


Figure 4-14: Photo of 1:12 model to show pentagon to pentagon interface.

in their permanent position. After frame assembly, gabions are built up around the frame and around where the bamboo connects to the foundation. The waterproof sheeting is placed over the whole frame, built up from the bottom. The full setup, including insulation is shown in figure 4-22

The insulation, internal walls and door are the final pieces to go into or on the dome.

4.4 Budget

The total estimated cost for one shelter is 525USD, a cost breakdown can be found in table 4.2; note that prices are approximate. The miscellaneous item is to account for pricing discrepancies and thus the budget gives an upper bound for cost.

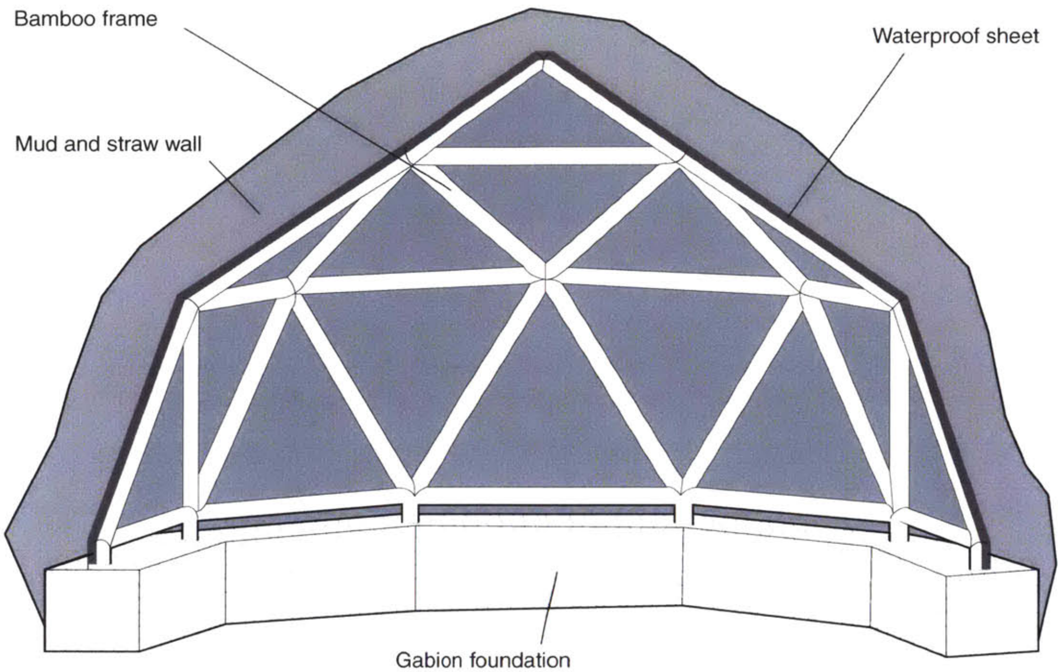


Figure 4-15: Diagram of full setup.

Item	**Cost (USD)**	**Source**
Bamboo poles	120	Local or import from China
Waxed chord	10	Local or import from China
Mud	-	Local
Straw	65	Local or import from China
Chicken wire	-	Local or import from China
Loose rocks or rubble	-	Local
Waterproof sheeting	100	Import from China
Latrine	80	Import from China
Internal wall fabric	20	Local
Misc.	120	n/a
Total	**525**	

Table 4.2: Table to show cost breakdown.

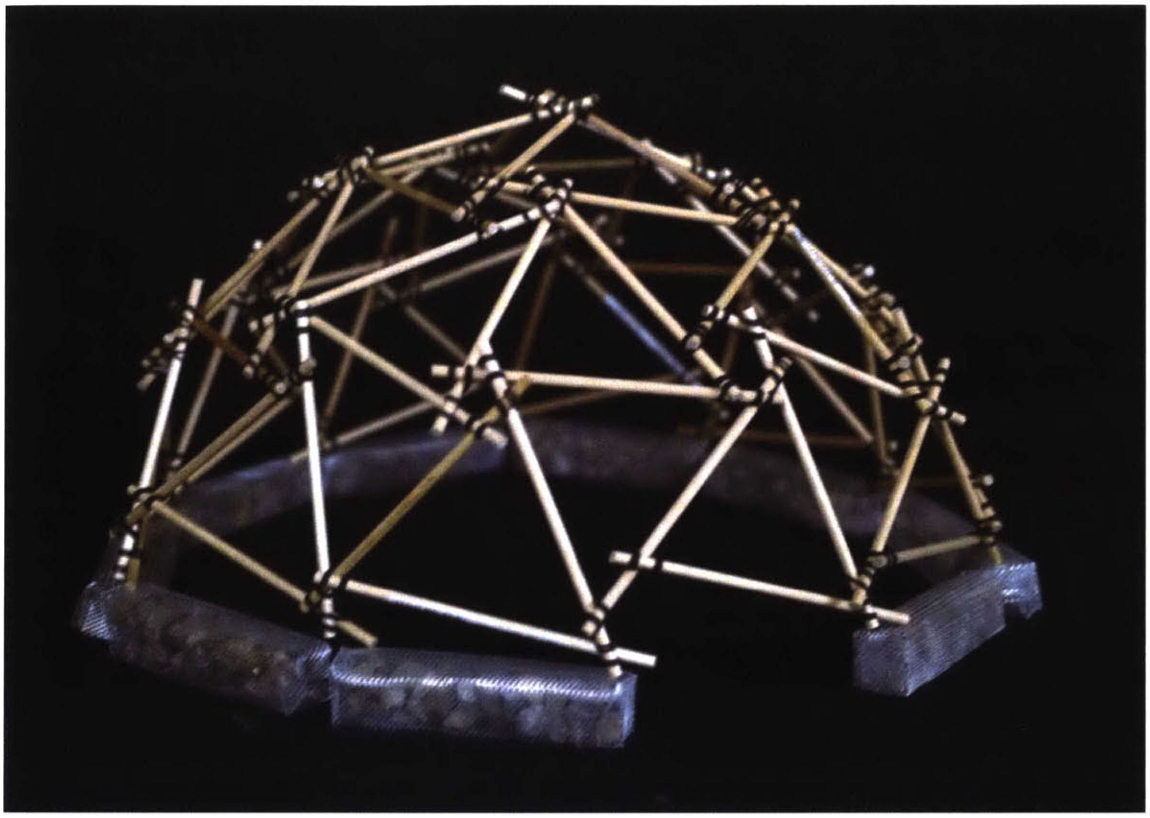


Figure 4-16: Photo of 1:12 model.

4.5 Prototyping

A 1:12 scale model was built in order to gain a better understanding of the build process for the dome. The 1:12 scale model proved useful in that respect and also in breaking down the building process to making smaller, far less complex, pentagon substructures that all fit together in the same way.

4.5.1 Scale model

The scale model in figure 4-16 features gabions, close-up in figure 4-17, to give an idea of what the full frame would look like. Note that the scale model does not feature an augmented section to house the latrine.

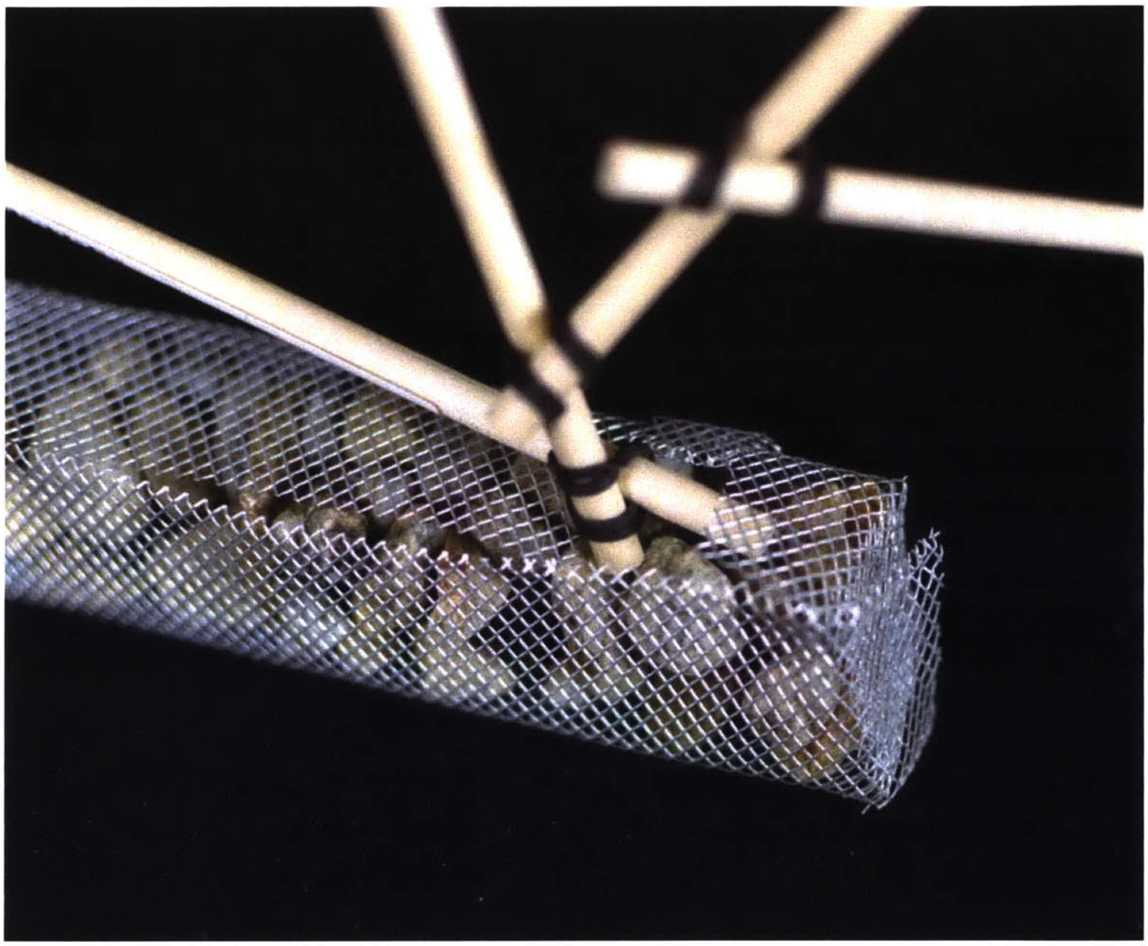


Figure 4-17: Detail of frame slotting into gabion.

4.5.2 Full scale prototype

A full scale model in terms of internal space was built using thinner bamboo. Much like the 1:12 model, the pentagonal assemblies were first constructed and then put together to form the whole dome.

During construction, it became apparent that is it important to avoid using too strong an elastic (or, in this case, too many rubber bands) around any particular joint because this made it difficult to harness the join flexibility and leeway in construction precision. See figure 4-18 where the bamboo is bowing because the too many rubber bands were used. It was also noted that through relaxing and tightening of the internal pentagonal reciprocal joints, different dome shapes could be achieved with the same length of bamboo. A tighter center join on a pentagonal piece made a pointier pentagon, a more relaxed join made a flatter pentagon. The full pentagonal piece in figure 4-19 has a very relaxed central joint and is therefore quite flat.

Once joints were finalized, zip ties instead of the intended waxed chord were used to hold the joints permanently in place. Figure 4-20 shows how a join was finalized with the use of a high strength zip tie.

While putting together the individual pentagons did not prove hugely challenging, getting all the pentagons to interface with each other proved somewhat messier. Figure 4-21 shows the jumble of rubber bands, zip ties and bamboo poles coming together at one point.

The final frame, see in figure 4-22, took a four-person team about four working hours to construct.

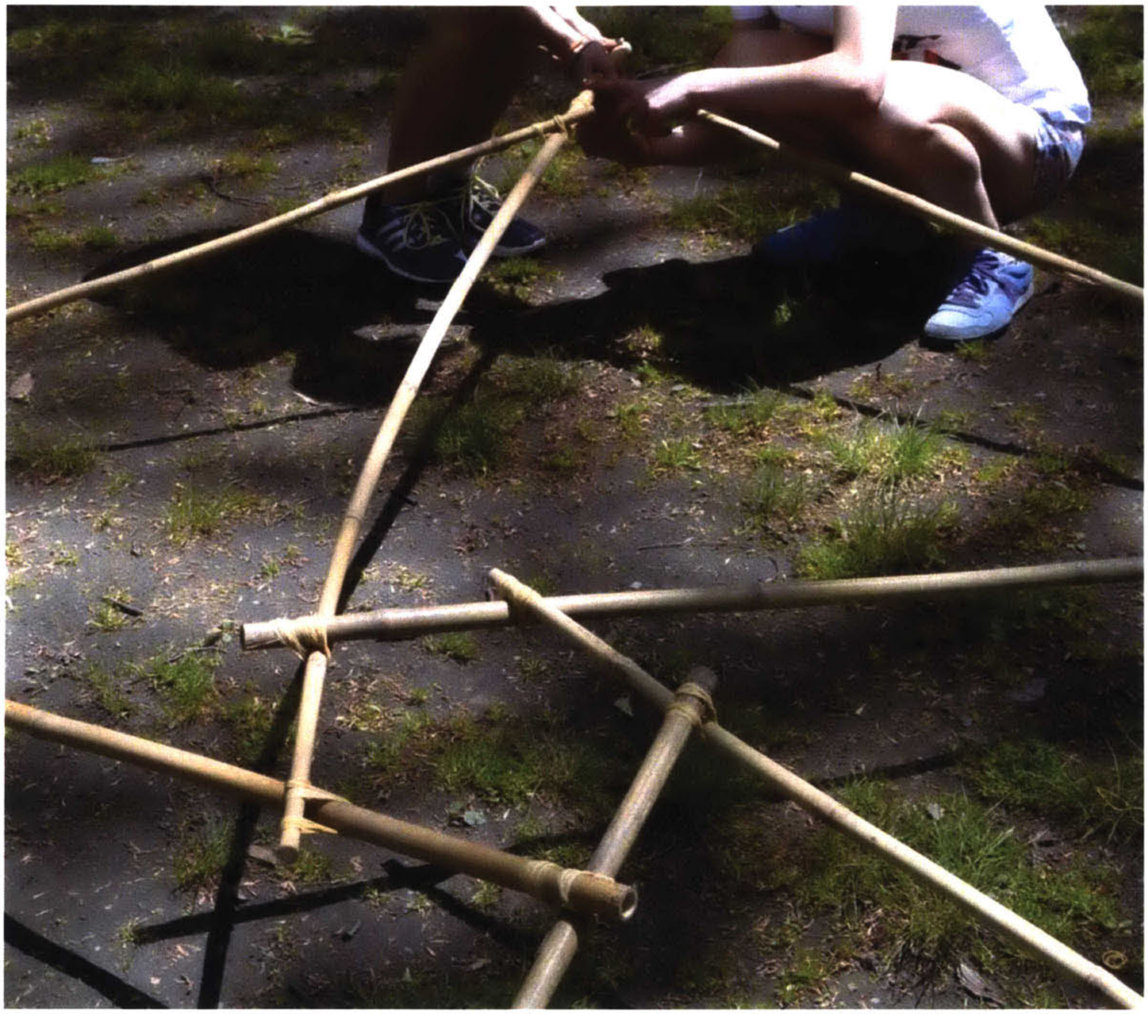


Figure 4-18: Photograph to show bamboo bowing.

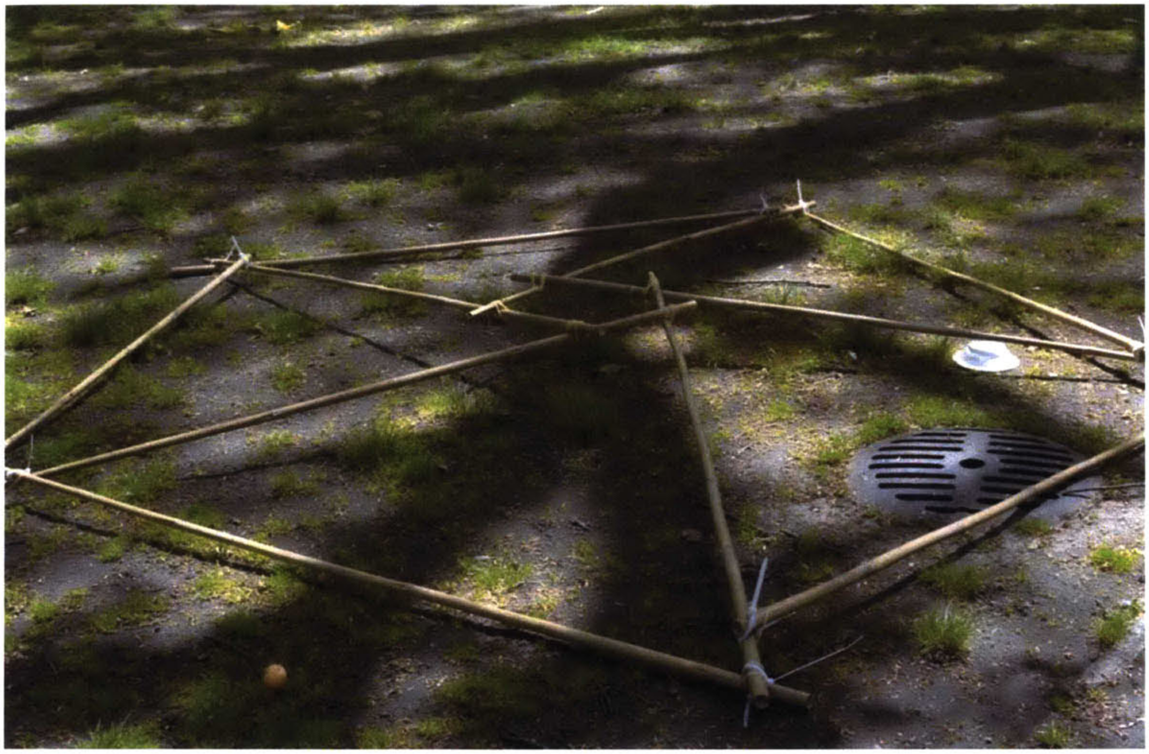


Figure 4-19: Photograph to show one pentagonal element.

Figure 4-20: Zip tie preventing join movement.

Figure 4-21: Photograph to show some of the messy joinery.

Figure 4-22: Photograph of full scale model.

Chapter 5

Conclusion

5.1 Analysis of results

Discussed largely in the preceding text, through analysis of the paper design and prototyping, structural, cost, construction and shelter lifetime hard requirements have been met. Cultural requirements, however would require further research into Nepalese culture around the Kathmandu area for verification.

Some soft requirements, such as power, have not been met, but have scope to be met with additions to the design. Solar panels, for example, are inexpensive and are not obstructive to the design.

5.2 Potential impact and contributions

The resulting shelter design harnesses the structural strength of the geodesic dome and the simplicity of reciprocal joinery. The construction breaks down the complex dome form into identical pieces which are easily constructed. The effectivness of the proposed design process is demonstrated through checking whether the resulting shelter design meets measureable outcomes like cost, structural integrity, and skill level required to construct. In addition to a successful design, the requirements process makes determining design effectiveness easier.

5.3 Future work

There is huge scope for future work in developing this design; building a full prototype and ultimately implementing the design are possibilities. On a smaller scale, I am confident that adding a safe power system can be done at very low cost, as such, future work on integrating solar power into the design is possible.

Future work could be on using the requirements to develop an actual rating system that could be used on many different t-shelters.

Lastly, stepping out to the bigger picture; implementing this design process for a different situation, perhaps for Syrian refugees, and analysing how well the end design functions would be a good way to test the design process.

5.4 Final remarks

Transitional shelters are a fantastic resource for displaced people whether it be for natural disasters or political unrest. That being said, thoughtful design can turn a quick fix into a long term solution. Transitional housing has potential to become permanent housing and, in the long term, shape a community of displaced people, both geographically and socially, making intelligent design yet more important.

The design process for transitional housing outlined in this thesis is a precedent for raising living standards for those who need it most in a more efficient and sustainable way.

Appendix A

A.1 Interview notes

A.1.1 Interview participant one

Privacy Visually sealed, shut out what is happening inside

Inside People would like private space, less common further out. Kathmandu higher than rest of country

Like an apartment here Room for parents, just one room for the kids, separate room for kitchen and bathroom. Living room less important. Typically people will just go to one persons bed room. Kids would just go to parents room. 4 room or corridor house. Usually you can hear, usually just visually private

Sometimes families just live together in the same house, 3 generations. Usually married, stay in house, stay in groom's house.

Marriage means girl goes, boy brings someone to the house.

Nuclear family pretty standard

Community events Not hugely isolating to have small number of houses in locality. Not a big problem. If people could be close together, they would.

Two boys, if house not big enough one might move out/both move out. Depends.

Social stigma "I don't think so" - can't find being modern is preferential. Outside, not so sure. Culturally designed houses are looked on as icons of strength. Kathmandu everyone is trying to be westernized, especially in our generation. Progressively the generation that has gone by becomes more westernized.

Big windows cannot look into someone else's plot of land. Windows have to be small - check this.

Labor is 'cheap' comparatively. No one builds their own house in Kathmandu. Door leading into shelter should have lock from both sides. Individual rooms not necessarily. Padlock or key system.

Just front door. No heating or cooling. Even in cold areas heating isn't a thing, light fire, heat selves up. It's nice.

Power is often cut off, schedules, no power in evenings. Daylight spaces mostly.

Villages, stick small solar panel. Usually charge a battery directly. Wary of dependence.

Very mountainous, can't really walk from place to place, everything is farther from it than it seems. Have about 100 or over language, most are completely different. Nepali is national language, speak at home.

A.1.2 Interview participant two

So far, it seems to be that central heating is not commonplace even in Kathmandu. But what are t he cooking options available to most people in Kathmandu? What does a typical Nepalese kitchen look like?

Yes, central heating is extremely rare in Kathmandu and I'm not even sure if there is one in any of the houses in Kathmandu. For cooking, most of the families use Liquefied Petroleum Gas, which comes in Cylinders (you can google image search Nepal Gas and you'll see all the pics). Others who can not afford to have the Gas Stove (starts from about \$10), Deposit for the cylinders (about \$25), or refill the gas (about \$14), use kerosene stoves (stove can be bought for about 5). Use of electric heaters is growing after the economic blockade by India in the recent months. However, the power shortage could reach up to 12-15 hours a day in dry seasons (almost all the electricity is hydroelectricity) so it's not viable. This is in Kathmandu. In remote places, most of the people still use firewoods to cook and I believe this is much more than 80% in villages. A kitchen comprises of stove (or fireplace) and cooking pots. Refrigerators are making into the kitchen but for most of the folks in rural area, it's a luxury beyond their imagination. A big part of the country still lacks access to electricity. Now, TV is making more into the household even in rural Nepal and if they do not have electricity, they use solar power for it. After refrigerator, even few people have microwave. And outside Kathmandu, it's extremely rare. Oven to bake is unheard of in Nepal. Very few cities have running water given by municipality. Villages have communal taps and or wells where people have to go to fetch water. In southern place, where the altitude is low, people have tube wells to draw the underground water. In Kathmandu, the water is very scarce and almost everyone purchases drinking water in jars. Most of the plates are made up of steel, which is strong and cheap. China is luxury and families in Nepal might have it.

How easy is to get a kerosene stove?

Kerosene stove is easy to get, but now more and more people can afford LPG Gas, so it's slowly phasing out of the market.

A.1.3 Interview participant three

Surya meeting

Sophomore

Pokharah - look up

Last two years in UK. Always in boarding school near home (same city).

City: Owner house has separate rooms. A lot of people rent houses, but will rent only one or two rooms. Grandparents in same house. Stay with parents if not at boarding school. 2-3 beds in the same room is not awful, but would prefer not to.

Village: Not a lot of privacy, kids sleep with parents. Grandparents in the same house. Once you're married you have your own room. 2-3 beds in a room.

City houses typically concrete, can't hear that much. Houses in villages made form mud and stones; mud and stones just found. They make their own houses.

Windows, people don't mind big windows. A lot of building your own house, usually hire an engineer. People build houses on their own land.

A lot of houses in city are concrete; not many wooden houses. Concrete just flat concrete on roof. Old type houses use tiles, stones used as tiles.

Liquid waste to gutter, drainage open. Solid waste piles up, some trash collection sometimes

Bathrooms: Expected, waste from bathroom. Scientific toilets, Chinese toilet, make a pit in own land, composting toilet. Check for city; definitely acceptable for rural.

No heating in general, lots of insulation. Sometimes use of fire, less common in cities. Cities nowadays people have heaters, central heating is not a thing. Electricity in rainy season lots of power cuts (3-4 hours a day), dry seasons, 14-16 hours power cut per day. Almost everyone has a phone (solar panel) lots of people have internet. Villages people have phones, but no internet. Cities different story.

Western ideas are not pushed away. Accepting of new techniques.

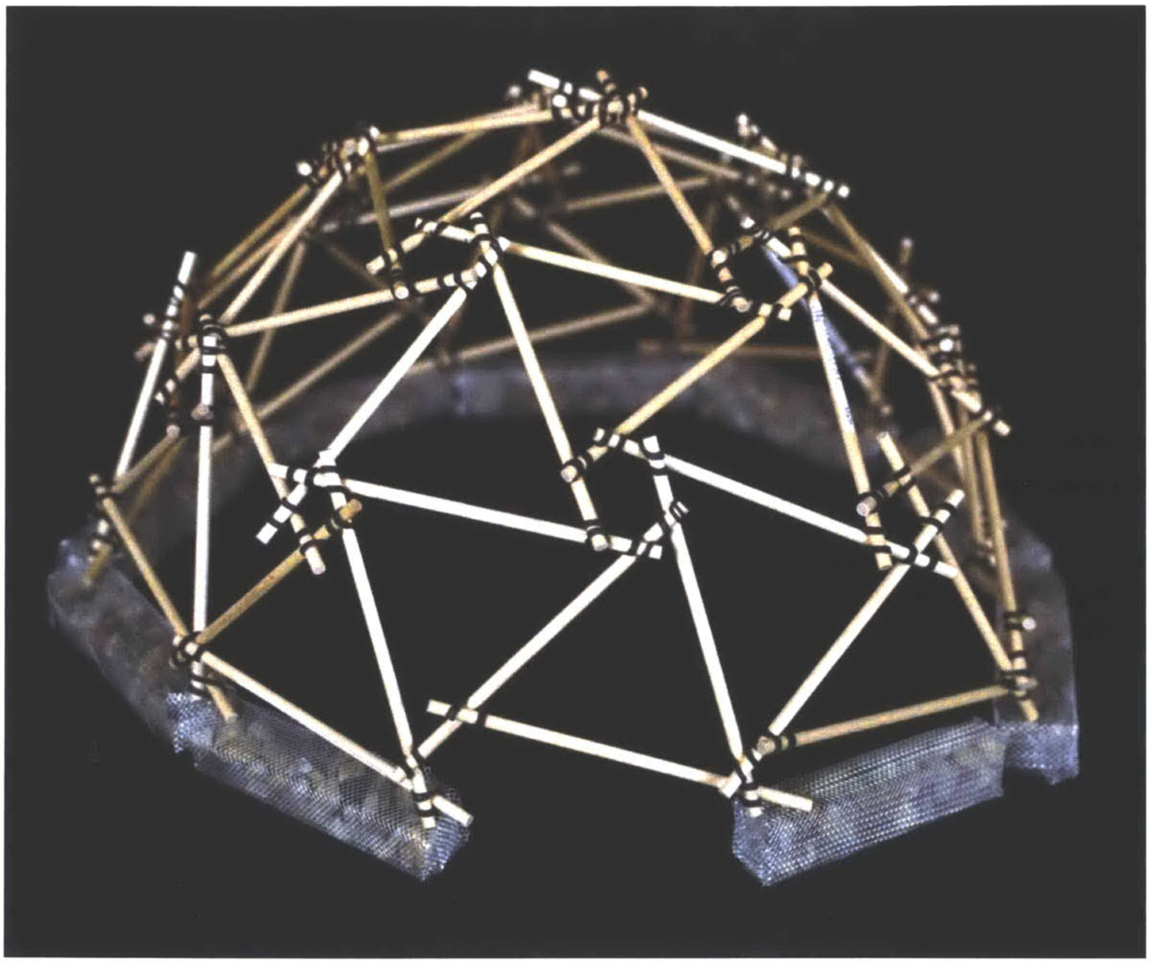
Usually people don't build own houses in cities. A lot of people have some idea of how to build, owners do help build to some extent. House to be made in their way if building own house; tell engineer what he wants.

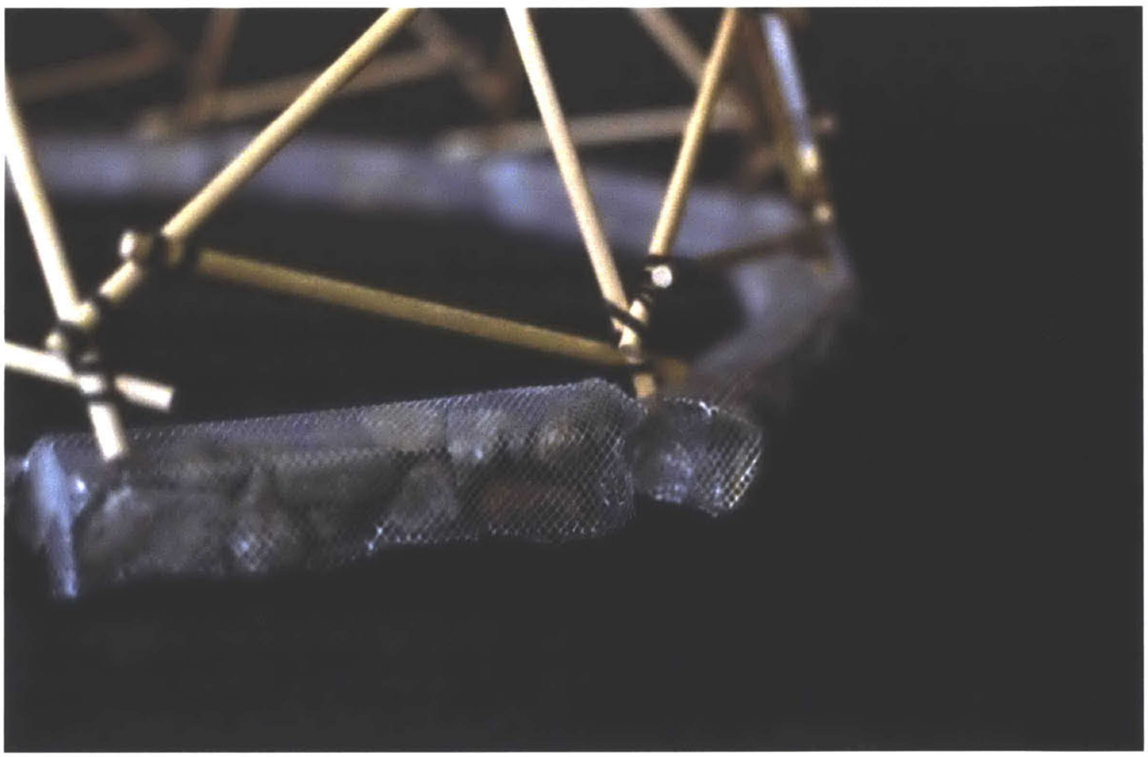
Locking door is kind of expected also for safety.

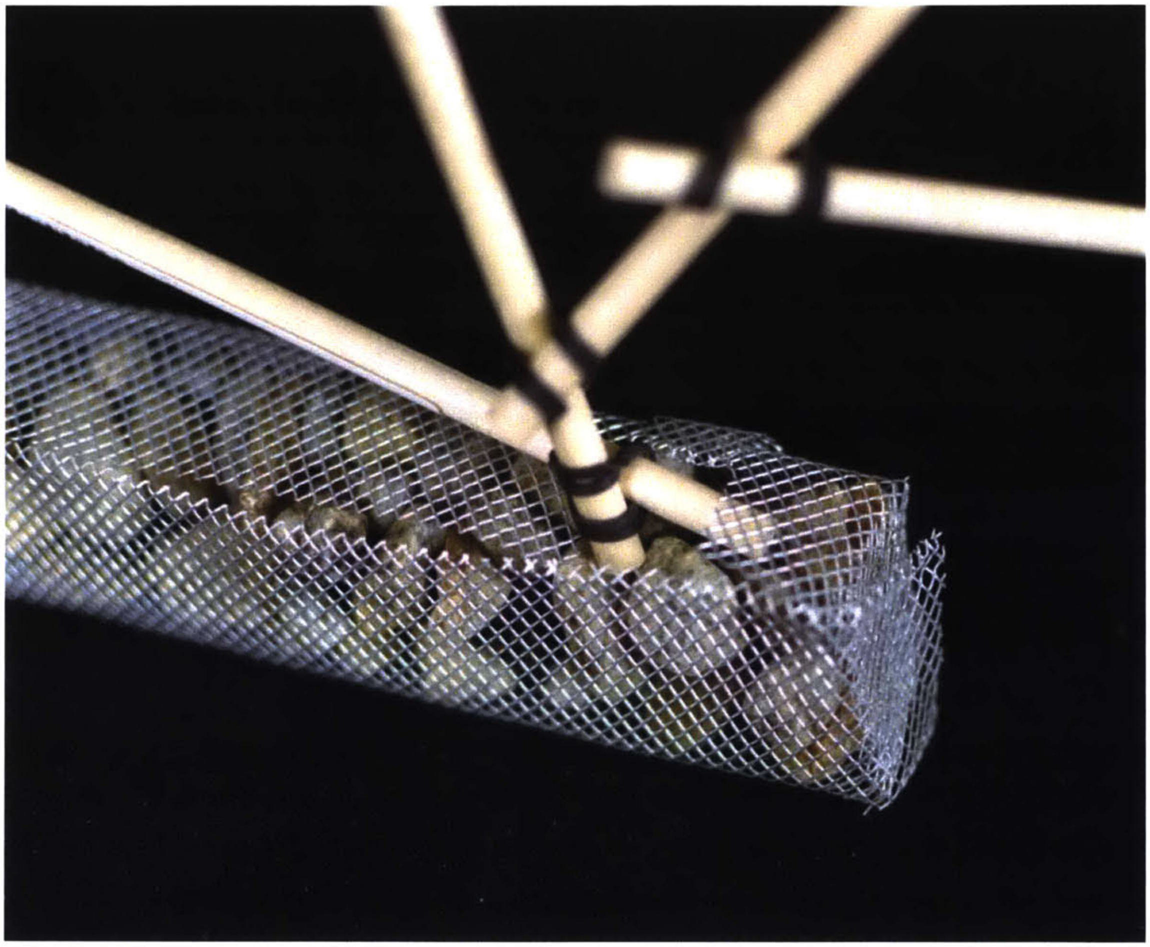
Curtain instead of door not really a thing, but acceptable for a short period of time; proper door should become available.

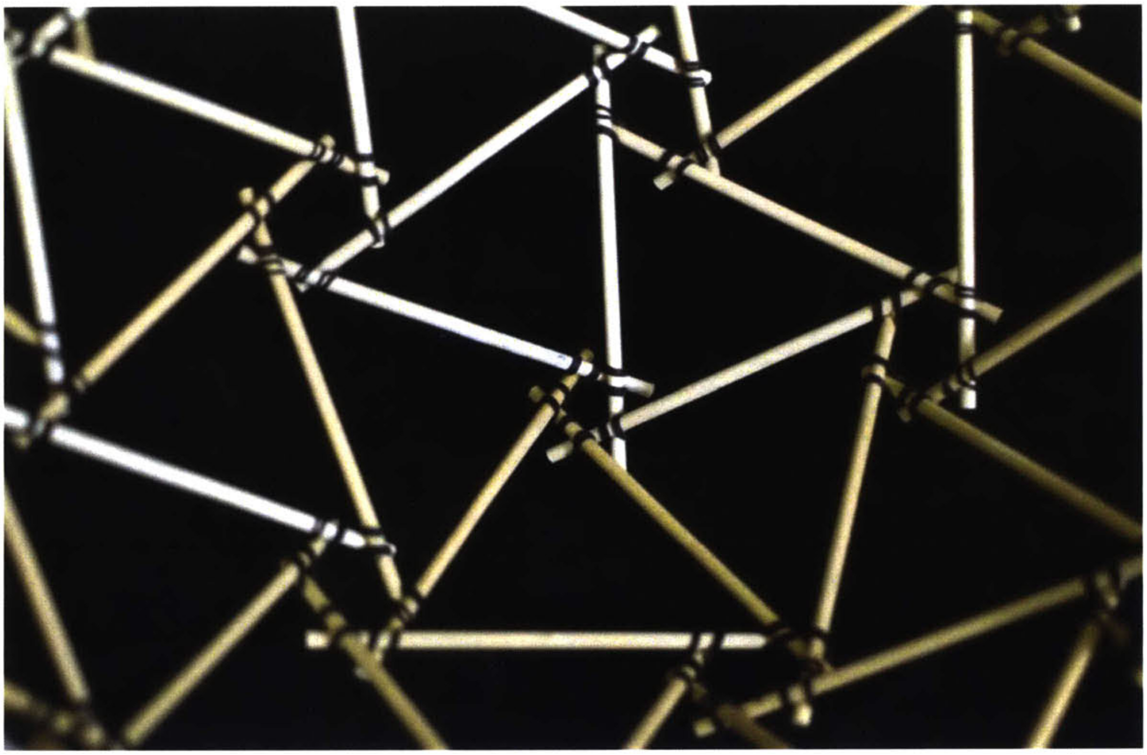
Toilet always inside in cities, different in village

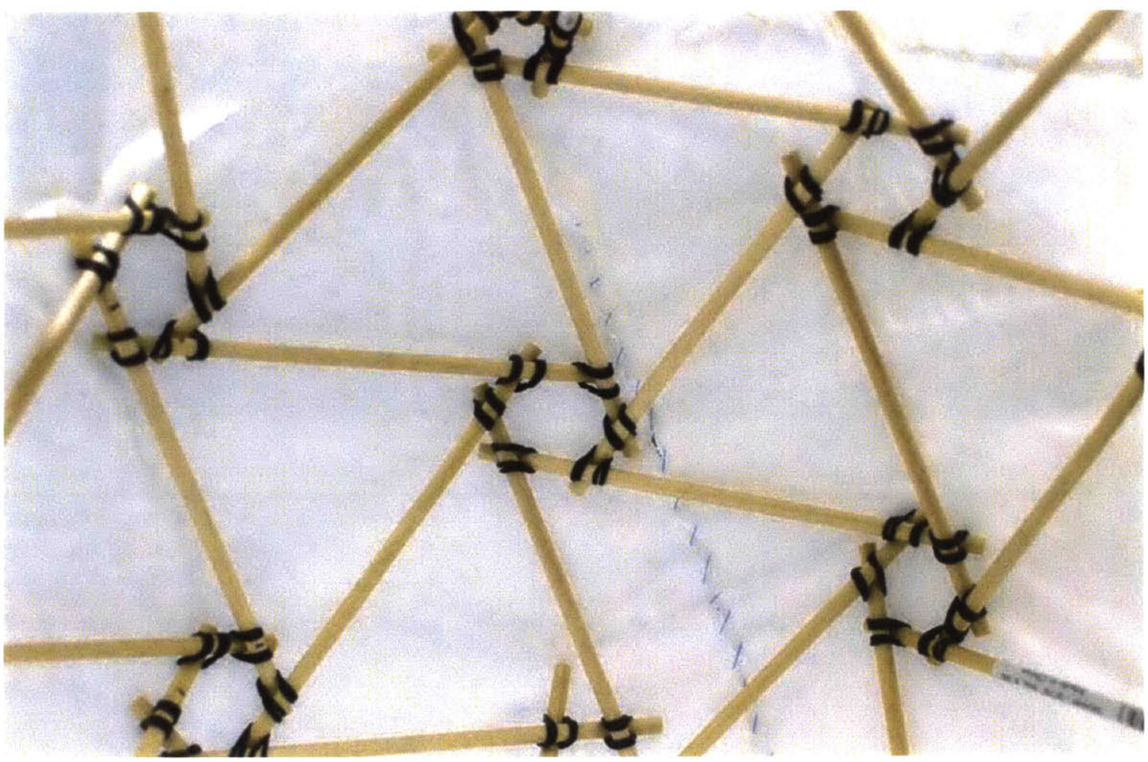
A.2 Model photographs

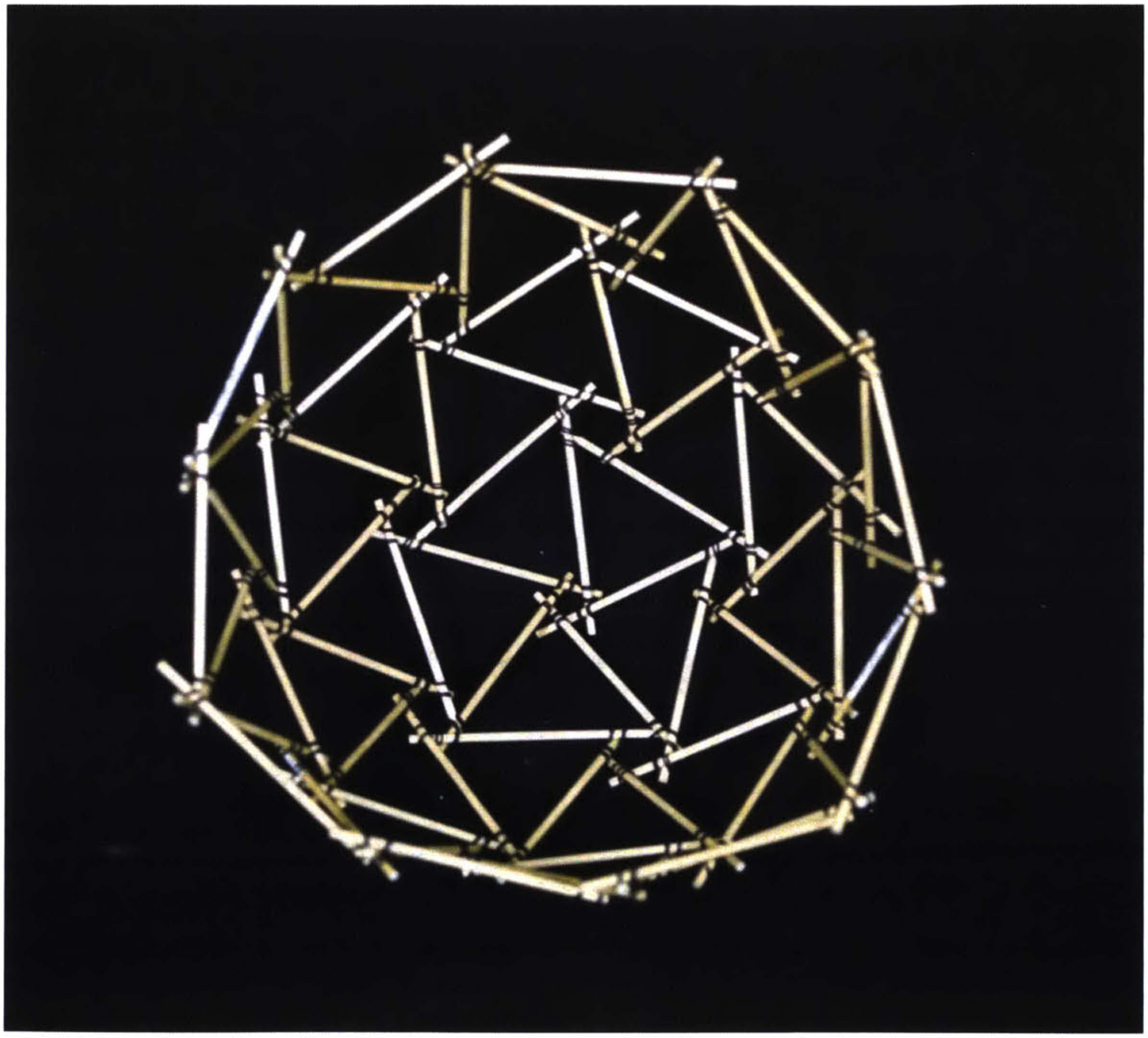


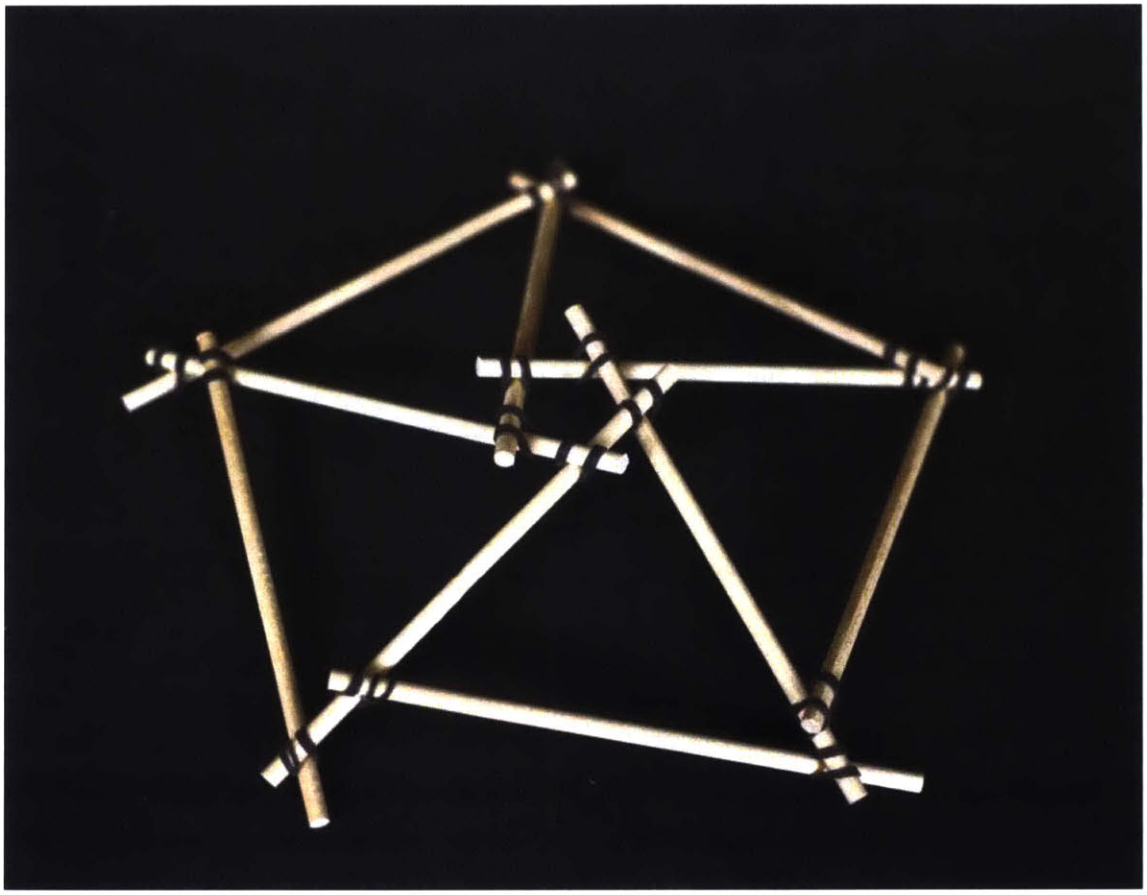


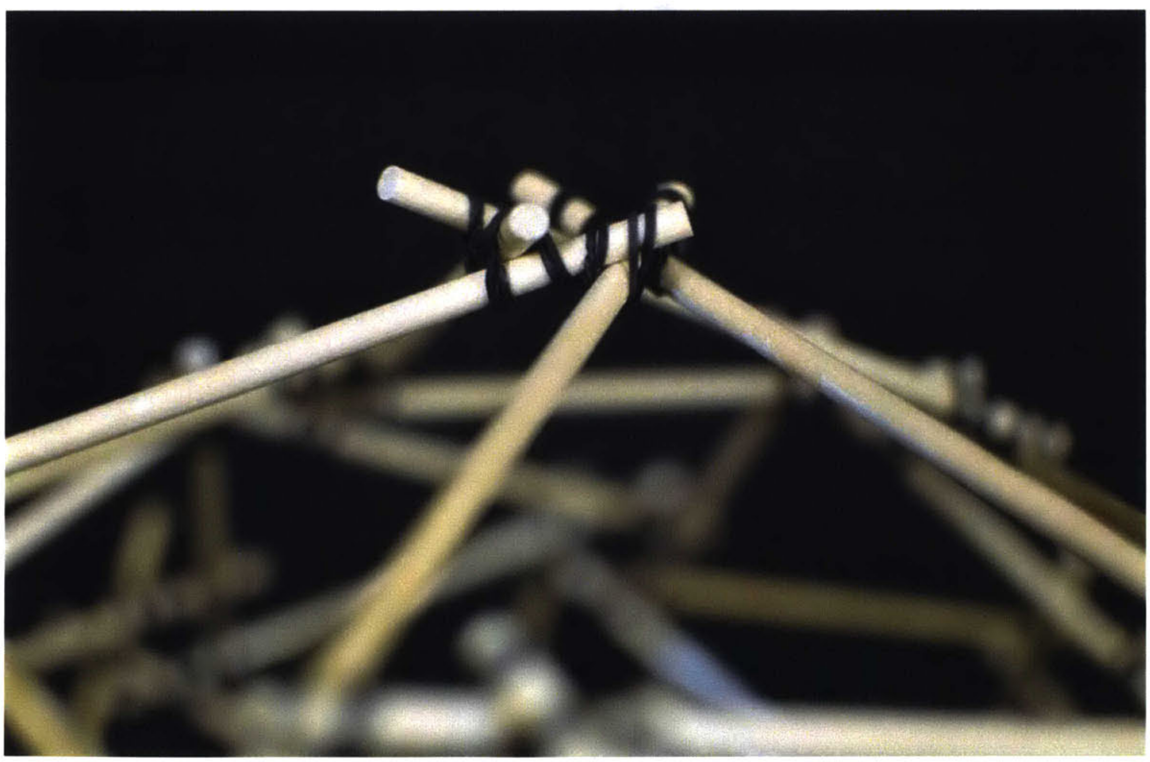












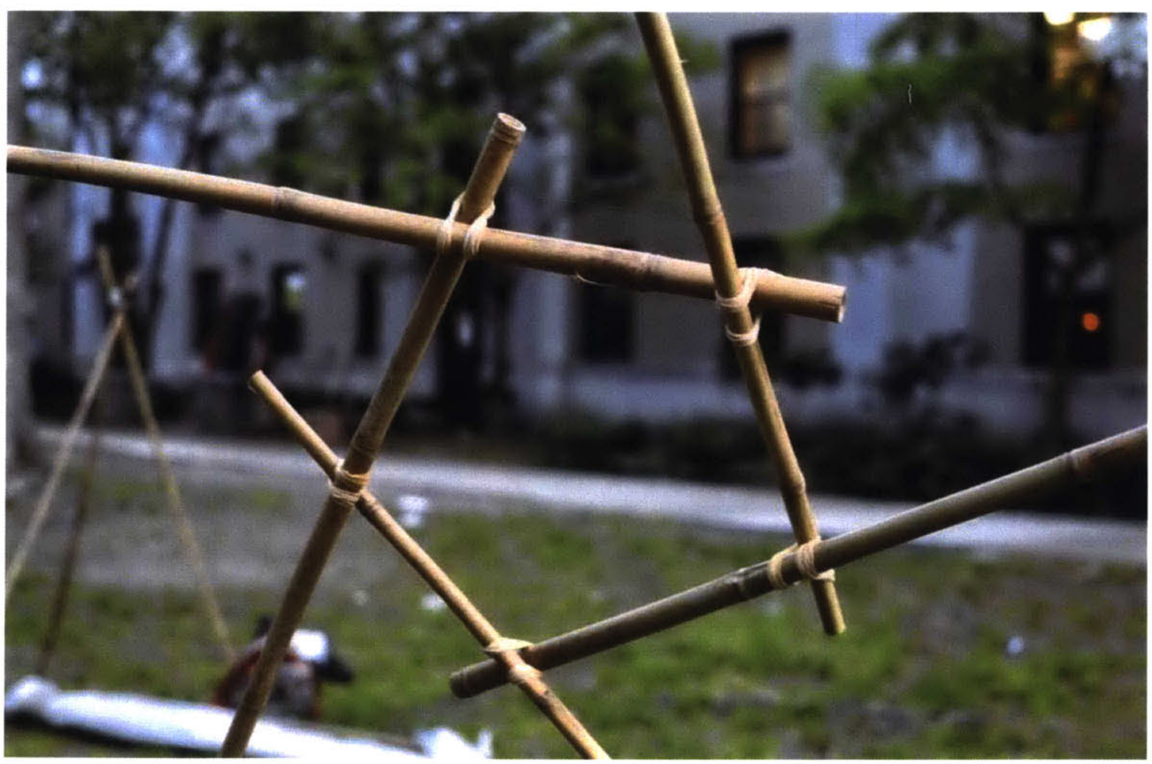


Figure A-1: The makeshift 'tripod' made of bamboo and rubber bands that was used to capture a time lapse of the building sequence.

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