APTH: the Aluminum Plastic Tarp House

The Four Freshineers: Team 2

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Mission Statement:
This project was designed to solve the housing crisis faced by displaced individuals following typhoons in the southern region of China. In order to generate a feasible solution, certain constraints as well as basic human needs had to be taken into consideration. The following Mission Statement was developed:

“Our Company focuses on providing durable, semi-permanent (up to 10 years) shelter relief for individuals affected by typhoons in the coastal southern region of China with minimal disturbance to local unaffected communities and habitats. We strive to maintain affordable, easily constructable, easily transportable, sustainable shelters that accommodate a minimum of six individuals in order to positively impact and improve the quality of life for refugees.”

Context and Customer Need Development:
As a team, the engineering students took a research based approach to help better understand both the environment in which the shelters would be implemented and the people the shelters would be housing. A plethora of sources were consulted in order to gain a more diverse perspective of China’s landscape, culture, and climate.

Through the researching process it was learned that China’s population is unevenly distributed throughout the country with the densest areas concentrated in the eastern part of the country bordering the East China Sea (“Population”). Upwards of 600 people per square kilometer inhabit these densely populated areas. These numbers are staggering when compared to the western part of the country where the average is around 50 people per square kilometer. According to statistics gathered in 2014 by the World Bank, the total population in China was over 1.36 billion which far exceeds the mere 318 million United States citizens (“Global”). Because China is so heavily populated, relocating communities after natural disasters can be a significant challenge. The only viable option for relocating refugees would be to set up temporary shelter-communities in the Northwestern regions of the country.

Generally speaking, China’s age populations are evenly distributed on the spectrum infant to elderly except for a significant peak in individuals aged 25-54 years old according to the Index Mundi studies conducted in 2014 (“Demographics”). Because different age groups have varying needs, understanding the age demographic of the refugees will influence building decisions and reconstruction efforts.

China has a diverse landscape. The eastern and southern region is not only home to the most populated area but also to the country’s agricultural center. In the event that the food supply should be destroyed, alternate food sources would have to be established in order to provide for the many millions (“Geography”). Generally typhoons occur in Western Pacific and East Asian regions which includes Taiwan, South China, South Korea, and Southern Japan (Hays).

When a natural disaster such as a harsh typhoon hits China, the devastating impact is undeniable. The strong storm wind gusts slam through buildings and structures causing physical damage. It is estimated that a typhoon would destroy 50% of the effected property in its wake (“Typhoon”). Thousands find their homes destroyed and have no choice but to relocate
elsewhere. After local communities suffer such uprooting, they often do not receive the medical attention required and many citizens face starvation (Devaney). The infrastructure loss due to typhoons from 1992-2007 was expected to be $28.34 billion with an average annual loss of $0.54 billion ("Typhoon").

Typhoon season ranges from early summer to early autumn coinciding with the monsoon season in Southeast Asia and the wet season in Eastern Japan. The peak typhoon season lasts from June to November. Deaths and injuries were a result of tornados induced by typhoon Mujigae in China. Seven people were killed and 223 injured by the damaging storm. In Zhanjiang city where the typhoon landed, gales and downpours brought on telecommunication blackouts and cut off power and water supplies to most affected areas ("Devastation").

Typhoon Chan-Hom struck mainland China. It was recorded as the most powerful typhoon to hit China since 1949. Due to the devastating effects of the typhoon, over 960,000 residents were forced to flee coastal cities and head inland. Transportation was interrupted due to extreme winds up to 200 kmph. On average, these displaced persons remained in temporary locations for five years before being able to return to the remnants of their homes ("Evacuates").

Infrastructure is a top priority for the Chinese government. Their government has long recognized that a modern economy runs on reliable roads, rails, electricity, and telecommunications. Between 2001 and 2004, investments in rural roads have increased by an annual 51% growth. There is a tremendous growth in the electricity sector with an annual growth of 9.2% lines (Bai et. al.). The Ministry of Finance (MOF) in September published details for 206 proposed projects, worth a total value of 659 billion yuan ($104 billion), which included constructing an expressway in Beijing ("Infrastructure").

“Central, Southern and Western China are also highly susceptible to flooding, and the country is also periodically subject to seismic activity” (China weather). The summers are moderate, and winters are mild with very little rainfall. Occasionally, cold air from the North will bring frost at higher elevations. Summers are wet at higher elevations, with mild rainfall in valleys. The southwest has the mildest climate in China year round. (BBC)

Mountains compose 33% of the landscape, plateaus 26 percent, and hills 10 percent. This accounts for nearly 70 percent of the country's land surface (Geography of China). The inland region in Southwest China is hilly and mountainous and descends to the eastern coast. The Yangtze River, one of China’s largest rivers, runs through the Southern part of the country. (Geography of China)

China is very abundant in both plant and animal resources and naturally occurring minerals. Although China is very rich in natural resources, the “per-capita natural resources” is extremely low. South China’s farmland accounts for 36.3% of the nation’s total and contains 82.3% of the total water. (Natural Resources)

While China is still making strides to improve their healthcare system, many rural areas experience inequalities with regards to healthcare costs, quality, and availability (Kahler). Citizen dissatisfaction led to a big push in 2000 to correct these inconsistencies. In April of
2009, the new $124 billion healthcare reform plan was implemented. It is expected to cover the entire population by the year 2020 (Kahler).

Mandarin is the official language of China. Mandarin is based on Beijing dialect and other dialects spoken in northern areas of China. Students are taught Mandarin in their school, and it is used as the mother tongue by most people (“Chinese Language”).

Race is a concept which classifies human beings according to broad physical characteristic such as skin color. The natives of China, Japan and the Eskimos belong to the Mongolian or yellow race (“Race”). The Chinese have a rich culture that includes intricate architecture, music, literature, and ancient philosophy. Because of the incredible document keeping, the old cultural customs are still well known today. Most of the societal values are derived from the teachings of Confucianism and Taoism.

China is the largest consumer of electricity in the world. The Chinese government is forming partnerships with various public and private limited enterprises and energy producers worldwide in hopes of appeasing the quest for energy. Data from the World Bank shows that 99.7% of Chinese citizens have electricity. However, in northwestern China and rural areas, about 3 million people are still off the grid. Though the major part of generating electricity comes from burning oil and coal, China is looking for greener and renewable forms of energy. For example, the 569 wind turbines along the Yangtze River produce 5,470,000 kilowatts of energy which help power some local communities (Lu).

China has abundant naturally occurring elements having a market share of 51% in the supply of raw materials. Approximately 23% of these elements are the rare earth metals are found in China. As a result, the country holds a global share of 97% in the production of rare earth metals. The main mineral sources found here are iron ores in Liaoning region and zinc in Yunnan region (Wrenn).

Our company decided to reach out to a secondary consumer, the All Hands Volunteers (All Hands) Nonprofit Organization, and partner with them to have our product reach those in need. All Hands is a newer organization having been created in 2006. The organization does not restrict its outreach to a specific geographical region, instead, the volunteers follow disasters in order to provide relief for disaster victims. Some of their previous work has been in Southern Africa, South Asia, South America, and North America. Some of its most recent efforts followed Typhoon Haiyan that struck the Philippines in November of 2013. This typhoon caused severe damage to the local Leyte communities. All Hands Volunteers started providing basic relief (foods), debris removal, and deconstructing unsalvageable structures. As time went on, All Hands Volunteers continued providing relief by constructing many houses for the storm victims who had lost everything. Because of these efforts, the organization has valuable experience dealing with typhoon destruction and is well versed in what it takes to heal an affected community. To date, All Hands has donated more than 1 million hours of volunteer work, built more than 1,900 homes, had more than 31,000 volunteers travel to disaster areas, and led more than 60 relief projects. The Organization’s’ motto is to “Rebuild and Recover”. They have a fairly consistent relief strategy of providing basic fast relief first then escalating efforts to
provide more permanent relief. The All Hands Volunteers move into devastated communities, help provide relief, AND check up on the communities they have previously helped. This makes this organization a perfect fit for our company since we aim to provide semi-permanent housing. They really focus on the communities’ needs and try their best to accommodate them all. Ultimately, All Hands was chosen because of its previous experience, recognition of other important relief aspects such as comfort and food, and their ongoing commitment to recovering communities.

The customers have both basic and complex needs. The students attempted to take all aspects into consideration throughout the designing process. Coinciding with Maslow’s Hierarchy of Needs, the most essential needs, level one of the pyramid, are shelter, sleep, food, water, and fresh air ventilation. The next tier, level two of the pyramid, contains the needs of community, property, family, and self-purpose. Above those come the needs of privacy, intimacy, and belonging. The pyramid is topped with the need for achievement followed by self-actualization and acceptance. All of these needs can be accommodated thanks to the partnership between All Hands and our company.

**Concept Generation Summary:**

When developing the first prototype initial ideas were brainstormed individually. Later we convened to discuss the pros of the individual shelter designs and contrasted them with the needs of our customers. We then selected our top three designs that satisfied the most needs. The standard requirements were that the shelter must accommodate six people, must be durable when exposed to China’s climate and weather, and must not encroach on any religious or environmental boundaries. Other customer needs focused on in our designs can be found in Table 2 of this report.

Below in Figure 1 and Figure 2 are images of some early designs as well as three of the final design contenders.
In order to help us unbiasedly determine which design best suited our customer needs, we used a weighted scoring matrix. Six of the top customer needs were selected and given a corresponding weight based on the importance that aspect bares. Once the weights were assigned each shelter was assigned a value for each category on a scale from 0 to 5, 0 meaning the shelter failed to meet the criteria and 5 meaning the shelter exceedingly met the requirement. The rate was then multiplied by the weight in order to generate the weighted score for each category. All the weighted scores from each category were added together into a total score. The matrix used is shown below in Table 1. Matrices are a valuable tool when it comes to decision making however they do not make the decision for you. Our group did end up selected Shelter 1 which coincidentally scored highest on our matrix.

Table 1. Solution scoring matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Concepts/Our Solutions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shelter 1</td>
<td>Shelter 2</td>
</tr>
<tr>
<td>protection from water</td>
<td>25%</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>living space</td>
<td>25%</td>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td>affordable</td>
<td>20%</td>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td>assembly time</td>
<td>15%</td>
<td>3</td>
<td>0.45</td>
</tr>
<tr>
<td>ventilation</td>
<td>10%</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>lightweight</td>
<td>5%</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>TOTALS</td>
<td>100%</td>
<td>3.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Test Report Summary for Prototype One

For the first prototype, as seen in Figure 3, was built with a cardboard frame to resemble the metal frame and covered with cereal box to resemble the fabric which makes the walls and roof of our actual house. After building the prototype the company realized that the house would be very small to hold 6 people. The prototype did pass most of the tests. Here is the testing plan for prototype one.

Table 2. Summary of prototype testing

<table>
<thead>
<tr>
<th>User need/feature/requirement</th>
<th>Test</th>
<th>Testing result</th>
<th>Pass/fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>Subject structure to “wind test” by putting the prototype in front of a fan on high speed.</td>
<td>Withstood the fan speed &amp; paper crush test</td>
<td>Wind test: Pass&lt;br&gt;Crush test: Fail</td>
</tr>
<tr>
<td>Cost</td>
<td>Average cost of the design should not be over $900</td>
<td>Under $1000</td>
<td>Pass</td>
</tr>
<tr>
<td>Waterproof</td>
<td>Prototype placed under the sink to determine water leaks</td>
<td>No major water leaks in the design</td>
<td>Pass</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Place hand on one side of the house and feel the airflow</td>
<td>Fresh air is able to enter/exit</td>
<td>Pass</td>
</tr>
<tr>
<td>Privacy</td>
<td>Enclosed structure and capable of repelling light</td>
<td>Light did not enter the house after shutting windows and door</td>
<td>Pass</td>
</tr>
<tr>
<td>Community</td>
<td>Maximises space so more shelters can be near each other</td>
<td>A shape that maximizes land plot space</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Figure 3. Prototype One in the Making
Hot gluing the roof of Prototype one.
1. Durability

The durability test into two parts. Part one was the Wind Test and part two was the Crush Test. For the wind test the company placed the prototype in front of a high speed fan to test if the any parts were lifting off. There were no noticeable damage to the prototype after the test. The prototype passed the wind test. For the crush test the company placed stacks of paper on the prototype to see how much weight it can withstand. The crush test did not go as they expected. Prototype crushed on one side with 4 stacks and paper and completely after 7 stacks. The prototype failed the crush test.

![Figure 4. Testing prototype 1 Wind and crush tests](image)

2. Cost

Looking at the average income of the chinese population the students estimated that a cost less than $500 would be feasible for them to purchase the house. After the prototype was built, the cost the company estimated it would take for production was $400. It passed the test.

3. Waterproof

For the waterproof test, the company placed the prototype under the sink running water over it. They found that there were no noticeable leaks in the prototype and the water did not enter the house from out. The prototype pass this test.

![Image](image)

4. Ventilation

For the ventilation test, the company kept fan under the prototype to see if the air was going out of the door and windows. Similarly they placed the prototype in front of the fan to check how much air was passing through the windows and door and checked this airflow by placing their hand near windows and door.

![Image](image)

5. Privacy

For the privacy test they wanted the house to be totally enclosed for others to not see what is happening in the house. They closed the windows and door of the prototype and shine
light on it to see if anything is entering. The light did not enter the house. The prototype passed the test.

6. Community

For this test the company wanted to build their house as small as possible without compromising the personal space each person would prefer in the house to fit many houses in a camp. From the estimates, they estimated the house to be 750 ft$^2$. As the camps sites are much bigger in areas, they assume that many of these houses can be fit into a camp site. Therefore the prototype passed this test.

Concept Refinement Summary

After they built their first prototype they realized that some assumption they made would not work in real life. The design of the house did reduce potential living space that could be provided by expanding the dimensions of the design. The height of the house was too low for the people inside to feel comfortable. Looking at the crush test they can see that relying the strength only on the cardboard frame was insufficient.

Looking at the constraints of our first prototype the decision was made to increase the space and the height of the second prototype. As the first prototype could not withstand the crush test the material of the walls of the actual shelter will be plastic, as shown in prototype 2, instead of fabric modeled by prototype 1. The frame of the house was made stronger by including 3 more bars in the design. The first prototype was designed to be mostly triangular to provide protection against high speed winds and the overall height at the peak of the prototype was 8ft. Unfortunately, having such a short peak height greatly reduced the living place for people inside. The decision was made to increase the peak height to 10ft while also adding a flat roof section to maximize space. An image of the final sketch for prototype 1 is shown below in Figure 5.

![Figure 5](image)

**Figure 5.** This shows the final sketch of prototype 1

It is important to note that this sketch does not have the modified side walls and top panel.
Test Report Summary for Prototype Two

The company’s second prototype did meet most of the designer expectations and consumer needs as it passed most of the tests. Increasing the living space by expanding the base dimensions and making the plastic bottom paneling taller raises the standard of living. It is also assumed that making these changes will create a stronger frame meaning the design should be able to support more weight in the crush test. Increasing the height of the plastic panels could also allow for further design development where connecting pieces could be made to connect multiple units together. With these improvements, the cost for the 2nd prototype was more than what we expected to be, but it is believed that this prototype will be both a more durable and a more appealing long term solution than the prototype one. Figure 6, below shows images of prototype 2.

Cost Analysis

The cost estimate for Prototype 1 was about $200. Unfortunately, this does not accurately reflect the costs of prototype 2. Because of the material choice changes made, the cost of prototype 2 worked out to be approximately $425 dollars per unit. As units are purchased in bulk, the price is expected to decrease by some appreciable margin. The $425 cost accounts for the price of all raw materials, price of repair materials such as patches etc, necessary adhesives, and marginal cost for the raw materials to be shaped into necessary pieces.

The materials selected for the final prototype (and for prototype 2) were a ABS plastic sheeting. This plastic material is known for being rigid, tough, and for its low cost. Also, if purchased in black it helps block harmful UV light. The second material selected was aluminum metal. Aluminum is characteristically lightweight, rust retardant, relatively abundant, and inexpensive. The third material selected was a lightweight, durable canvas fabric. This was selected based off historical context. For many decades animal hides have been used in tee-pee like structures to provide protection from the elements.
**Consideration of Human Needs**

Looking at hierarchy of needs, the second prototype did mostly satisfy all of those needs. Starting with physiological, the house is well ventilated for fresh flow of air and there are enough windows for light to get in. The company even incorporated skylight by placing windows on the roof to provide natural lighting to the house if electricity is not provided. The house can hold upto 6 people which is the size of an average family so they need not worry about individual space. Coming to safety, the house can be shut well from all the sides so there is privacy for people inside the house from others outside. The triangular structure of the house would reduce a lot of wind pressure due to the typhoons. As the house is modular and can be built by any common man and is easily repairable which would satisfy esteem and self-actualization needs. As the house is designed to be as small as possible without compromising the space, more houses can be fit into the community which could keep a lot of people together in one assorted space on camp.

**Considerations of Overall Camp/System**

The shelter was designed to be modular and mostly built out of a rigid plastic frame and fabric. Therefore the production of these materials can be down with the available resources in any country and can be packed compactly for the transport of this modular home. An ikea style of setup mechanism was inspired and incorporated into our house design for common people to follow through the instruction and easily set up their house. The house is designed to only occupy only a space of 30ft x 25ft which can incorporate many houses even if the campsite is small. A lot of people being together after a disaster full fills the first community need and the size of the house allows it to do so. The windows could be open when the weather is good to see what is happening in the community or talk to the people passing by. The company’s rough estimate for the cost to purchase this shelter is $900. The cost is relatively less for individuals but charities can help them to subsidize cost. The materials picked for this house is often readily available in many places for the manufacturers to easily obtain. therefore production cost for this house would be less which brought down the price of the house.

**Re-design Ideas/Thoughts and Conclusions**

Ideally, prototype 3 would be fairly similar to prototype 2. Because prototype 2 met most of the essential needs customers would have, prototype 3 would focus on making the living standards more comfortable and practical. When redesigning for prototype 3, the design would incorporate solar panels to provide electricity for the house so that the individuals can enjoy technology and electrical appliances from the comfort of their new homes. A rainwater collecting and storage system could also be incorporated to collect fresh rainwater for both the occupants and community members. Another idea would be to create alternate panel connectors so that two units could be merged together to create a larger living space.

The shelter was designed to be small enough to fit many into a larger community while large enough to accommodate 6 individuals. The materials selected are both readily available and relatively inexpensive. Due to the lightweight nature of the materials, this house design can be
compacted making it easy to transport. Making our prototype we realized what mistakes we made in our initial drawing and had to make revisions to make the structure feasible.

**ALL References:**


"Is Chinese Considered a Race, Nationality, or Both?" *Yahoo! Answers.* Yahoo!, n.d. Web. 27 Jan. 2016. (Race)


