Slanted Roof

Team #3: iCab

Tara Fowler, tkf5064@psu.edu
Emily Helm, ejh5398@psu.edu
Jesus Figueroa, jaf5880@psu.edu
Prachi Chandna, pkc5111@psu.edu

Dr. Sarah Ritter
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Mission Statement

On April 25, 2015, there was a tragic earthquake in the small country of Nepal. It reached 7.8 on the Richter scale and there were many subsequent aftershocks throughout the entire country. This earthquake left many people homeless and in need of a safe place to live. The shelter needed would have to withstand the climate, primarily the rain in the summer season, of the country and be able house families comfortably. This shelter also would need protection against any future earthquakes that may happen, yet still be considerably cheap. In addition, the shelter needs to be able to be repaired by the locals with the resources that are available to them. iCab was tasked to build this exact type of shelter. The team aims to provide adequate shelter to displaced persons in Nepal who were affected by the recent earthquake. The shelters will be very affordable and easily repairable. They will benefit these persons in keeping them safe from nature as well as any surrounding wildlife. The design of the shelters will be easily transportable and long lasting. They will benefit every type of person affected, from single men or women to large families.

Context and customer need development

In order to build a shelter that is suitable for the people of Nepal, research is needed to be done about the location at hand. Nepal has four distinct seasons that happen in the same order and in the same months as they do in the US. The summer season (June-August) is very wet as it rains almost everyday, which is something to consider when building a shelter to last multiple years. Otherwise the seasons are not very harsh and do not go to the extremes temperature wise. Nepal's topography is cluttered with the mountains of the Himalayas, including the tallest mountain in the world, Mt. Everest. [1] The likelihood of earthquakes in Nepal may also trigger avalanches on any of these mountains.

Nepal is right above the country of India, the founding land of Hinduism, and as a result of this, most Nepalis are Hindu, with Buddhism being the next popular religion. With these two religions dominating, the country is full of their influences and symbols
decorating buildings, landmarks, vehicles, etc. The government has been run by the Shah Dynasty ever since the unification in the late eighteenth century, first as a monarchy and now under a multiparty democracy. The national language spoken in Nepal is “Gorkhali” or “Nepali,” which is derived from Sanskrit. Although this is the “national language” of Nepal, most ethnic groups have their own sort of language that is often put before Nepali and can cause communication problems. [2] These communication problems prove difficult in making directions for use of a product, in this case instructions on how to assemble the shelter.

As mentioned before, the Shah Dynasty primarily led Nepal throughout much of history. Starting in 1768, Prithvi Shah conquered the capital city of Kathmandu and unified the divided country. The government at that time was a monarchy. However, in 1846 the monarchy falls to a group called the Ranas, who isolate the country from the outside world. Over a century later in 1951, the Rana rule ends and the crown is returned only to be taken away again by a democratic constitution in 1990. The first prime minister of Nepal, Girija Prasad Koirala, was elected in 1991. [3]

Although Nepal has a modern government, their access to important resources is very limited. The country is landlocked with no surrounding large bodies of water. In addition, even though most people living in this country have access to water, it is not safe to drink. Many of these people have to rely on brooks that populate the mountains of this area, which are also not always safe considering contamination by pollution. [4] Since Nepal is a very poor country, most of its citizens are very hungry and malnourished. Most work in agriculture, but production has been decreasing, which leaves them with inadequate food supply. [5] There is also very little energy consumption across the entire country. [6] The fact that there is very limited access to many resources or energy in this developing country makes the design process all the more challenging, since they do not have most of the things that are here in the United States. Even though it does not have many essential resources, Nepal has plenty building materials, such as wood, metal, stone, etc. [7] These can be used to easily repair a damaged shelter.
In order to make and actually distribute the shelter, the help of a secondary consumer is needed. In this case, the secondary consumer is the organization CARE. CARE is a nonprofit charity that has over 880 projects in over 90 countries around the world. They have been involved with the people of Nepal since 1978 and they were directly involved when the Nepal earthquake struck. Three years prior to the 2015 earthquake, the organization had an emergency preparedness meeting, and also staged an earthquake simulation just two weeks before the major earthquake happened. They have helped over 10,000 people get emergency shelter already, so they are a large asset for the completion of this project. [8]

In addition to knowing the basics of the country and finding an organization well suited for the task at hand, it is important to note the basic customer needs of the product. It was decided that the two most important needs are the shelter being weather resistant and spacious. The order then goes as follows: affordable, transportable, lightweight, and long lasting. For the shelter to be weather resistant, it must be able to withstand the endless rain of the monsoon season and the possibility of another earthquake, and to be spacious it would have to comfortable fit a family of six or more. The shelter can not cost too much since the people it is made for live in a poor, developing country. Also, it needs to be easily transportable so that it can be moved wherever necessary without an extreme amount of effort. Being lightweight ties into being compact and transportable, so that the minimal amount of people have to lift it. Lastly, this shelter needs to be able to last a substantial amount of time without having to do extreme repairs or replacements. These customer needs certainly need to be taken into account when designing a shelter for an area like Nepal.
**Concept generation summary**

iCab’s shelter had to fit different specifications according to the customer needs mentioned in the last section. The specifications are as follows:

- the prototype was to cost under $5
- the total area needs to accommodate 3.7 square meters per person according to the 1:15 scale
- the weight of the cardboard prototype needs to be under 0.35 kg
- the prototype cannot fall apart when shaken or absorb water
- it needs to fit in a 6 cm x 19 cm x 3 cm dimensioned box
- the structure needs to sustain the weight of 4 reams of paper

With these specifications in mind iCab needed to come up with design ideas for the actual shelter prototype. At first individual brainstorming ideas were created to promote creativity, and then the group shared each idea and came up with even better ones.

*Figures 1, 2, 3, 4 & 5. Early design drawings for the first prototype*
The figures above include some drawings that the team came up with and ultimately ended up testing. This test includes a selection matrix, that measures the probability of a design to meet the required specifications. It includes the weight of importance of each need and a scale of how well each design matches the need. In this case the scale was 1-5, with one being the least compatible and 5 being the most. A number from 1-5 is placed for each need under each shelter design chosen and then it is multiplied by the percentage of weight chosen. The shelter with the highest score at the end is the “winner” and can help easily decide which is the best design to use. An example of iCab’s selection matrix is shown below.

Table 1. Selection matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Rating</th>
<th>Weighted scale</th>
<th>Rating</th>
<th>Weighted scale</th>
<th>Rating</th>
<th>Weighted scale</th>
<th>Rating</th>
<th>Weighted scale</th>
<th>Rating</th>
<th>Weighted scale</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordable</td>
<td>20%</td>
<td>2</td>
<td>0.4</td>
<td>2</td>
<td>0.2</td>
<td>4</td>
<td>0.8</td>
<td>3</td>
<td>0.6</td>
<td>2</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>Long-lasting</td>
<td>3%</td>
<td>4</td>
<td>0.2</td>
<td>4</td>
<td>0.2</td>
<td>3.5</td>
<td>0.175</td>
<td>3</td>
<td>0.15</td>
<td>4</td>
<td>0.2</td>
<td>2</td>
</tr>
<tr>
<td>Lightweight</td>
<td>10%</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td>4</td>
<td>0.4</td>
<td>3</td>
<td>0.5</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>Spacious</td>
<td>25%</td>
<td>5</td>
<td>1.25</td>
<td>5</td>
<td>1.25</td>
<td>3</td>
<td>0.75</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>Weather resistant</td>
<td>25%</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>1.25</td>
<td>5</td>
<td>1.25</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Transportable</td>
<td>15%</td>
<td>3.5</td>
<td>0.325</td>
<td>3.5</td>
<td>0.325</td>
<td>4</td>
<td>0.6</td>
<td>4</td>
<td>0.6</td>
<td>1</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in the matrix, the shelter that won was shelter four, which is pictured in Figure 5. Ultimately though, the shelter that the team picked was the design in Figure 2. This was because of the slanted roof to deflect and potentially collect rainwater, and the potentiality of having paneled walls (for a possible earthquake). The team then made advances in building this paneled shelter out of cardboard.
Testing Report summary for Prototype 1

Figure 6. Emily holding the completed prototype

Figure 7. Affordability testing results
Figures 8. & 9. Testing the prototype for water resistance

Figures 10. & 11. Testing the prototype using the crush test

Figures 12. & 13. Results from the crush test.
The group began testing the prototype after building. They ran six different tests to include all of the customer needs mentioned above. The first test was to see how portable the prototype was. To make transportation of the prototype easiest, it was determined that the panels, while stacked, should fit into a box that was three centimeters tall, 6 centimeters wide, and 19 centimeters long. Before attaching all of the panels together, the panels were stacked and measured thoroughly. The prototype failed because the roof had not been cut into panels and therefore did not fit inside of a box with the required dimensions.

The second test was affordability. Calculations for this test are shown in Figure 7. The group added up the total dimensions of each side and used the predetermined costs of cardboard to determine the total cost of the materials used in the building process. If the total cost of the materials was under $5, then the prototype was set to pass. After running the test and finding the total cost of the prototype to be $1.10, the group found that the prototype passed the affordability test.

The third test that the group ran was for spaciousness in the prototype. They first researched the standard comfortable living space and determined it to be 3.7 m$^2$, meaning that the total living space for six people would have to be 22.2 m$^2$. After building, the area of the prototype was determined to be 962 cm$^2$ or 64.1 m$^2$. The area of the prototype was much bigger than 22.2 m$^2$, so the prototype passed the spaciousness part.

The group then tested to see if the prototype was lightweight. They did this by placing the prototype on the scale. For the prototype to pass, it was decided it should be under 0.35 kg. The prototype weighed only 0.30 kg, so it passed this test.
The fifth test ran was to determine if the prototype was weather resistant. This included three different parts: shaking the prototype vigorously to simulate an earthquake - a pass would mean that the prototype did not split apart, pouring water on the prototype to simulate rain - a pass would mean that no water would penetrate the prototype, and placing the prototype in front of a box fan to simulate an intense wind - a pass would mean that the prototype was not affected by the air flow. *Figures 8 & 9* show the extent of water damage from the second part of this test. The prototype passed all three parts; it did not fall apart when shook, it was not penetrated by water, and it was unaffected by the air flow.

The final test iCab ran on the prototype was the crush test to see how much weight it could hold without breaking. The group decided that to pass, the prototype should be able to withstand the weight of four reams of paper, each weighing about 2.4 kilograms. The prototype held all twelve reams of paper as shown in *Figure 10*. Although this technically already passed, the team needed to have a definitive number of how much weight it could hold, so each teammate took turns standing on the prototype. Tara (*Figure 10*) and Jesus individually did no significant damage to the prototype, but when Emily stood on it, the panels of the prototype began to bend. *Figures 11 and 12* show the extent of the damage to the prototype. iCab determined that the prototype could withstand about 68 kilograms before collapsing.

After completing all six tests, the group reviewed the results and made a comprehensive summary of their findings, which can be found in *Table 2*. 
<table>
<thead>
<tr>
<th>User Need</th>
<th>Describe Test</th>
<th>What is “pass”?</th>
<th>Materials</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordable (See Figure 2)</td>
<td>Add up the dimensions of our shelter and then figure out the total cost from the preset costs of cardboard/foamboard/pressboard.</td>
<td>If the total cost of these materials is under $5</td>
<td>Calculator, Ruler</td>
<td>Cost of prototype materials: $1.10 <strong>PASS</strong></td>
</tr>
<tr>
<td>Spacious</td>
<td>Measure dimensions used and compare them to research of the area of a comfortable living space</td>
<td>If the area of our dimensions are above 3.7 square meters per person (22.2 square meters total)</td>
<td>Computer, Calculator, Ruler</td>
<td>it is much bigger than 22.2 sq m (64.1 sq m) (962 sq cm) <strong>PASS</strong></td>
</tr>
<tr>
<td>Lightweight</td>
<td>Weigh the prototype shelter.</td>
<td>If the cardboard structure is under 0.35 kg.</td>
<td>Scale</td>
<td>0.30 kg <strong>PASS</strong></td>
</tr>
<tr>
<td>Weather resistant (See Figures 3 &amp; 4)</td>
<td>For earthquakes: Shake the base of the shelter For rain: Pour some water on the shelter Also a fan provides wind simulation</td>
<td>If the panels do not disconnect, and if the water doesn’t penetrate the roof</td>
<td>Water, Human shaking, fan</td>
<td>Panels intact, and no water inside shelter <strong>PASS</strong></td>
</tr>
<tr>
<td>Transportable</td>
<td>Consider the dimensions for a large moving box and then decide if the shelter’s panels could fit in one or two of them</td>
<td>If the prototype fits in a box with the dimensions of 6 cm x 19 cm x 3 cm</td>
<td>Ruler</td>
<td>The roof is one whole sheet, so it would not <strong>FAIL</strong></td>
</tr>
<tr>
<td>Weight it can sustain (See Figures 10 &amp; 11)</td>
<td>Use the “crush test” to see how much weight the prototype can hold (how many 2.4 kg paper reams)</td>
<td>If the prototype can sustain 4 reams of paper</td>
<td>Rig, Reams of Paper</td>
<td>150 pounds or 68.04 kg <strong>PASS</strong> (See Figures 12 &amp; 13)</td>
</tr>
</tbody>
</table>
**Concept refinement summary**

After testing prototype 1, prototype 2 was designed using the 3D CAD software, SolidWorks. Based on the testing results of prototype 1, the team worked on specific areas where prototype 1 failed to meet the customer needs. According to *Table 2* of the summary of prototype 1 testing, the prototype failed to meet only one of the customer needs. The prototype failed to meet the criteria of being easily transportable and this was something that was kept in mind before designing prototype 2. Prototype 2 used the same dimensions, same criteria and same specifications that were used while making prototype 1. There were however, a few changes that were made to improve the model for prototype 1, in order to help it meet all the required customer needs. The reason prototype 1 failed to meet the transportable criteria was only because the roof didn’t have any built in panels and therefore it would be difficult to transport the roof with the rest of the model. In the design for prototype 2, the roof was cut into 5 pieces which were made into different panels each with a width of 7cm, as the whole roof was 35 by 30 cm. After the roof was cut into panels, the team decided to add a plastic sheet to the whole model which would be a kind of removable tarp, only to be used during the rainy season to prevent any water from coming in the house. After making the above change, the problem of transportation was solved; the whole model would break down into panels including the roof and the panels would be put in a box, which would be easily transportable. Moreover, the model for prototype 1 didn’t include any windows. The people in the house wouldn’t have had access to fresh air or sunlight and the house would have been very compacted with no breathing space. To correct this error, the second change made while designing prototype 2 was to add windows to the house for better ventilation and for better access to sunlight.
**Test Report Summary for Prototype 2**

Because prototype 1 passed the majority of the tests, iCab members decided they do not needed to make major changes to their design. However, they pointed out that the roof was required to be paneled in order to fulfill the transportable requisite. This was achieved by separating the roof into 5 panels that perfectly fit in the required boxes. Moreover, iCab members settled to change the material of their shelter to a stronger one; specifically StrongSide Vinyl Siding. Besides being an eco-friendly material, StrongSide Vinyl Siding is also long lasting and virtually maintenance free. It has a “Hurricane-Velocity Wind Resistance, that can withstand wind loads up to 253 mph in independent tests.” Not only is it resistant to termites, rodents, worm, marine parasites or other insects, but also it is resistant to UV rays. In addition, it is very easy to clean, while always maintaining its lightness.

If prototype 2 was tested, the results would be completely satisfactory. They would be expected to be favorable as shown in *Table 2*, with the difference that the Transportable requisite would be achieved.

*Figures 14., 15 & 16. Updated designs of prototype 2.*
Cost analysis

After adding up the dimensions of our shelter and then figuring out the total cost from the preset costs of cardboard, the cost of the cost of prototype materials came out to about $1.10. Moving on, the group dimensioned the actual shelter using the scale of 1:15 and calculated the cost of building one shelter. The group decided to use StrongSide Vinyl Siding as the main material to build the shelter. StrongSide Vinyl Siding cost $0.93 per sq./ft. and according to this data the estimated cost for the iCAB shelter would be around $883. Given the fact that there will be 1000 shelters built, iCAB took into consideration the discount that the company will give because of the bulk purchase and estimated that the total cost would come down to $750.

Table 3. Summary of cost estimation

<table>
<thead>
<tr>
<th>Area covered</th>
<th>Dimensions in feet</th>
<th>(Price per sq./ft.) X (Area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1</td>
<td>151.8 x 2.16</td>
<td>$141</td>
</tr>
<tr>
<td>Wall 2</td>
<td>7 x 17.25</td>
<td>$112</td>
</tr>
<tr>
<td>Wall 3 &amp; 4 (Part 1)</td>
<td>7 x 11.75 x 2</td>
<td>$164</td>
</tr>
<tr>
<td>Wall 3 &amp; 4 (Part 2)</td>
<td>0.5 x 2 x 7 x 2</td>
<td>$13</td>
</tr>
<tr>
<td>Roof</td>
<td>0.5 x 14.75 x 17.25</td>
<td>$236</td>
</tr>
<tr>
<td>Base</td>
<td>12.8 x 18.25</td>
<td>$217</td>
</tr>
<tr>
<td><strong>Total Estimated Cost =</strong></td>
<td></td>
<td><strong>$883</strong></td>
</tr>
</tbody>
</table>

*Figures 17. Shelter Material - StrongSide Vinyl Siding*
Consideration for Human Needs:

For iCab’s shelter, the group considered the hierarchy of human needs while designing, prototyping, and refining. First they considered the bottom of the pyramid, the basic physiological needs. For the camp, each cluster of shelters would share a community kitchen and bathroom to cover the needs for food and excretion. iCab also considered adding a way for each shelter to collect its own rainwater but they did not incorporate this idea into either prototype 1 or 2. It is possible that they will try a design before making the product available publicly.

The next part of the pyramid focuses on safety. iCab’s shelter has a lockable door and two closable windows. This allows the people living in the shelter to feel safe at night and to have privacy from other refugees in the camp. The shelter is also designed to endure the weather conditions of Nepal, including heavy rains and earthquakes, so that the people in this community can feel safe from other natural disasters.

The team then considered the need of love and belonging. The shelters are designed for six people to live together, meaning that a family of six can live together in the same shelter. The shelters do have a very large volume and can hold more than six people comfortably, according to the results of the spaciousness of the shelter. The camp will also be set up with groups of shelters forming a circle with the doors facing inward. This will give the residents of the camp more of a community feel so everyone feels like they belong to a group. iCab would like for the whole camp to feel comfortable with their neighbors and have the satisfaction that comes along with belonging to a group.
Considerations for overall system/camp

The main design of the shelter focuses on having panels on each side of the wall. So, when an earthquake occurs the panels can fall apart separately, rather than crashing down forming debris. These panels can be separated and stacked on top of each other to put into a box for easy transportation, with a total height of 2 cm. Being a good a measurement to the 6 x 19 x 3cm box. There will be five stacks of the panels, each stack for a wall and one for the roof. Furthermore, other than being easily dimensioned to fit into the box, the whole model only weighs 0.30 kg. The lightweight of the model helps with the ease of set-up and the dimensions help it to ease distribution and transportation.

The final design is made for single families to live at ease with their personal space and some privacy. However, the group decided to focus on the social aspect of the whole situation and considered the fact that all these people have just faced a tremendous amount of trauma. Therefore, it is important that they stay in close contact with each other and create a small community within themselves. To further aid this idea, the group decided to make changes in the placements of these shelters at the main site. The shelters will be placed next to each other in close proximity, wherein all the front-face of the shelters will point inwards forming an arc. This setup will include 5 to 6 shelters placed next to each other at distance of 6 feet. There will be 6 to 7 setups like the one described earlier, following the same arc formation. This will ensure the privacy of the families inside the shelters, but at the same time allows them to be part of a larger community from the outside. People will have the chance to communicate with other refugees and blend into a community that has faced the same trauma.

The shelters designed by iCab are not only for displaced people, but also for the secondary customer, CARE. The charity will be provided with the same shelter design and will be given temporary housing in one of the communities.
Re-design ideas/ thoughts and conclusions:

If another team would take over the project, iCab members would suggest them to always have in mind the constraints of the project. If one team is able to design and elaborate a product that suits all the needs and even exceed them, then the goal was achieved. The way to do that is by creating a product that fulfills a necessity, something needed that one can take full advantage of. One can not create a product without knowing the background of the customer and most importantly, their needs.

When building a third prototype the first thing to work on would be the possibility of making it even more lightweight. Because in several of the developing countries where the shelter will be used do not have an efficient transport system. Therefore, the shelter has to be lightweight as possible to facilitate its’ installation and transportation. Additionally, the new design would have solar panels in the roof, to provide electricity to the displaced people in case of need. We would try to make a modular design, to find a way to connect different shelters, so the people can easily accommodate them and have enough privacy. This system will also reinforce the sense of community among the refugees.

iCab’s dream prototype would be one that as said before, meets all the customer needs while respecting all the constraints. A lightweight shelter that could be used in different locations; from mountainous areas to flat ones, and bear different climates from being cold to warm. It should be low maintenance and durable, which can be exposed to different situations while always being safe for the individuals.
References: