Project X

Colin Krohto (cfk5093@psu.edu)
Jack Lindenberger (jal6078@psu.edu)
Dustin Torgersen (fjt5383@psu.edu)

Tune Squad
Group Number: 1
Section 22
Dr. Ritter
Mission Statement:

The goal of the Tune Squad is to provide safe, comfortable, and affordable housing to the displaced people of Papua New Guinea, such that they would be protected from the many impactful earthquakes. Papua New Guinea is hit, on average, with an earthquake every day (3) and these earthquakes affect freestanding houses in a major way. Aided by the engineering design process, The Tune Squad explored how to make the goal of safe, durable, and affordable housing for the displaced people of Papua New Guinea a reality.

Context and Customer Need Development:

The first step to finding a solution is defining the problem. In this case, the problem is the immense amount of displaced persons worldwide. The initial step is to determine the most impactful tragedy to a certain demographic of people. During the brainstorming process, the group generated a pool of ideas. It was then concluded that unavoidable natural disasters such as tsunamis, earthquakes, and floods caused the majority of displacement. After much discussion, displacement due to earthquakes was determined to be the most interesting disaster to combat. A country best fit for outside help would be one frequently hit by earthquakes. Papua New Guinea lies right on the edge of the Ring of Fire, a major faultline between tectonic plates. Due to its unfortunate location, the island is hit by an earthquake every day (3). The citizens of this nation live in constant fear that their houses will be destroyed by the next major quake. Because of this inherent fear, it was decided that the people of Papua New Guinea needed the most help. This process has taught that research needs to be done in order to better understand the situation behind a problem, which in turn helps direct towards the solution.

The name of the non-profit organization that can help implement the shelters is called Cuso International. It stations qualified volunteers in developing countries in order to help with any problems at end. This charity has operated all over the world with countries that include Papua New Guinea, Peru, Nicaragua, and the Democratic Republic of Congo. In some of these countries, tragedies happen every day, and it is rare to have a peaceful day. Cuso International does work for the community every day. The addition of this shelter project to its agenda could increase its prestige as well as increase worldwide awareness of natural disasters. For all of these factors, Cuso International was chosen to be secondary customers.

After finding the country and reason behind its citizens’ displacement, the next step is to generate ideas of what the customer needs for the shelter. Initially, each individual started listing all the things that were necessary for the house to fit the mission statement and, in doing so, a list of customer needs was created. This list was broken down into three separate categories: Requirements, Primary Wants, and Secondary Wants. The most essential customer needs, such as durability, repairability, affordability, spaciousness fit into the Required category. Items such as availability to electricity, plumbing, heating, and ease of assembly fit into the other categories of Primary and Secondary Wants. From here, the process of designing the concept of the appearance of the house began.
Concept Generation Summary:

*Table 1. User needs table.*

<table>
<thead>
<tr>
<th>User Need</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordable</td>
<td>&lt;$2000</td>
</tr>
<tr>
<td>Longevity</td>
<td>&gt;10 years</td>
</tr>
<tr>
<td>Minimal Minor Repairs (cracks, holes, etc.)</td>
<td>&gt;1 repair every 6 months</td>
</tr>
<tr>
<td>Minimal Major Repairs (panel replacement)</td>
<td>&gt;1 repair every 2 years</td>
</tr>
<tr>
<td>House Large Number of Residents</td>
<td>≥6 persons</td>
</tr>
<tr>
<td>Quick Assembly</td>
<td>&lt;18 hours</td>
</tr>
</tbody>
</table>

Figures 1-4: Design drawings from individual members of the Tune Squad.

Pictured on the previous page are a few of the designs that each one of the group members came up with. Some ideas that were created were too ludicrous to implement in the real world, but provided different perspectives on the final design.
The following abbreviations refer to the table that follows and can help to better understand how the group came to choose the house that they did.

D1 refers to the rectangular house that consists of square identical pieces.  
D2 refers to the trapezoidal pattern house without legs.  
D3 refers to the semisphere house.  
D4 refers to the house with legs that are designed to be in the ground.  
D5 refers to the semisphere house, but with a center pole in the middle.

R = rating  
WS = weighted score

Table 2. Matrix Summary

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>D1 WS</th>
<th>D2 WS</th>
<th>D3 WS</th>
<th>D4 WS</th>
<th>D5 WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>low cost</td>
<td>.2</td>
<td>4</td>
<td>.8</td>
<td>5</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>longevity</td>
<td>.2</td>
<td>3</td>
<td>.6</td>
<td>4</td>
<td>.8</td>
<td>3</td>
</tr>
<tr>
<td>minor repairs</td>
<td>.1</td>
<td>4</td>
<td>.4</td>
<td>4</td>
<td>.4</td>
<td>2</td>
</tr>
<tr>
<td>major repairs</td>
<td>.3</td>
<td>3</td>
<td>.9</td>
<td>5</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>6 residents</td>
<td>.15</td>
<td>5</td>
<td>.75</td>
<td>5</td>
<td>.75</td>
<td>5</td>
</tr>
<tr>
<td>assembly time</td>
<td>.05</td>
<td>5</td>
<td>.25</td>
<td>5</td>
<td>.25</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>3.7</td>
<td>4.7</td>
<td>2.2</td>
<td>3.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

After completing the scoring matrix, it was determined that the most optimal house for the design specified was D2, the trapezoidal house without legs. The scoring matrix shows that D2 only lost in one subcategory of longevity to D5 which was a similar design but with a center pole in the middle.
Test Report Summary for Prototype 1:

After much cutting and construction, the design came to life. The house was first constructed in SolidWorks in order to find the dimensions of each individual piece. With careful assembly, everything came together beautifully in the workshop. After construction, many tests followed. The Stair Roll Test, Drop Test, Crush Test, and Assembly Test are all explained in the following table.

Figure 5: Prototype 1

Table 3. Summary of prototype testing

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Test</th>
<th>Testing Results</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>Stair Roll</td>
<td>No visible damage was seen after the constructed house was rolled down 5 flights of stairs.</td>
<td>PASS</td>
</tr>
<tr>
<td>Repairability</td>
<td>Stair Drop</td>
<td>After being dropped from 1 floor, damages from landing on a piece of wood were repaired easily. Drop from 2nd floor showed no visible damage. Drop from 5th floor showed no visible damage. All repairs were quick and easy.</td>
<td>PASS</td>
</tr>
<tr>
<td>Repairability</td>
<td>Crush</td>
<td>After breaking under Jack’s weight of 180lbs in the first crush test, repairs were made and the house was able to support 250 lbs the second time before breaking again.</td>
<td>PASS</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>Time to Assemble All Pieces</td>
<td>The assembly of all the pieces of the shelter was to take within a one and a half hour time span. The group successfully accomplished this task by constructing the shelter in one hour and seven minutes.</td>
<td>PASS</td>
</tr>
</tbody>
</table>
Concept Refinement Summary:

The testing on Prototype 1 gave insight into problems that were inherent in its design and which could then be solved in Prototype 2. The previous tests showed that Prototype 1 had walls and a roof that were able to sustain heavy impact as well as a large load so these didn’t have to be taken into consideration when developing the second iteration prototype. However the testing did reveal a fatal flaw in the design, i.e. the connections between adjacent plates were weak and needed to be reinforced. Using previous knowledge from the development of the first prototype was essential to ensuring that all of the primary goals of the design were continuing to be met.

What was altered to reduce the problem but still maintain maximum space was attaching a reinforced ring to the second layer of the roof. This ring was placed high enough above the floor as to not get in the way of a person living in the shelter while also significantly increasing the strength of the roof’s joints by decreasing the overall pressure on a single joint.
Test Report Summary for Prototype 2:

Prototype 2 will be better at meeting the needs of the customer as compared to Prototype 1. Prototype 2 has two key design features that will be greatly beneficial to its success as a shelter. The first improvement is the added support ring on the second layer of the house. With this added ring, Prototype 2 will be much more structurally sound than Prototype 1 because the ring will evenly distribute any pressure that is placed on the roof. This combined with the ring’s ability to take pressure away from the weakest parts of the roof, i.e. the joints, means that the shelter’s structural integrity is vastly improved. Along with these increases in structural support, the internal support ring also gives the shelter's occupants more versatility to arrange their new home. The rings is extruded slightly inward allowing form items to be hanged such as pots/pans, clothing or curtains for compartmentalization of the house. Being able to compartmentalize the house means that one can get more privacy as an individual. Privacy fits in
under “Security” on Maslow’s Hierarchy of Needs, so this is a necessity for families to have within a shelter.

The other notable design difference from Prototype 1 to Prototype 2 is the addition of legs for the shelter. In the first design there were no legs as building a sturdy frame was the primary goal. With Prototype 2 this design feature was able to be added due to more focus on how to prevent any damage from earthquakes. The idea behind the legs is to make their resonant frequency completely out of sync with the frequency of an earthquake. This can be done by adjusting the length of the legs to counteract the frequency of an earthquake. This would make the shelter sway significantly less than if it were in direct contact with the ground, meaning less damage to the occupants’ belongings, as well as less damage to the shelter as a whole.

*Figure 13: Prototype 2*
Cost Analysis:

The first prototype came out to be 4.53 ft$^2$. Given that the cost of cardboard is $0.25/ft^2$, the cost of the Prototype 1 is $1.13. In the Prototype 2, a concentric foamboard ring in the ceiling was added for increased structural integrity. Four cardboard columns were also added to reduce the impact of earthquake. The cost of foamboard is $0.50. Given the added specs, the new total area is 4.87 ft$^2$ of cardboard and 0.625 ft$^2$ of foam board, making the new cost $1.53.

The expected cost of one shelter would be $2,789.84 using acrylic plexiglass sheets(7) as the siding and a steel bar as the concentric ring(10). This cost is much higher than the initial requirement of less than $2000. However, this price is unrealistic given that this number is taken from an online website that sells customized sheets of plastic and metal. If this shelter were to be implemented, the manufacturer would be mass producing sheets customized for the shelter, so the price would come down steeply due to bulk discounting. It is impossible to get exact figures, but one shelter by itself will be much more expensive than 1000 shelters purchased with bulk discounting.

The total cost of maintenance for this shelter is no greater than $500, due to its easy-fix design, where a damaged panel can easily be swapped out for a new one. Realistically, this repair cost will come down even further with the application of bulk discounting from the manufacturer.

The materials used would be an acrylic plexiglass sheet for the shell of the shelter, as well as a steel bar for the inner concentric ring in the ceiling. These materials would no doubt have to be imported to Papua New Guinea, as there are unfortunately very few resources available within the small country itself. Importing the materials will bring the cost of each shelter up accordingly.

Consideration of Human Needs:

As Papua New Guinea is already very much a self-sustaining society, the location of the shelter neighborhood will determine the citizen's' ability to satisfy the “Physiological Needs” tier of Maslow’s Hierarchy of Needs. They must be located near food and water sources to satisfy these needs. The shelter itself will satisfy the next requirement of “Safety and Security”, as it protects the residents from the sheer number of earthquakes that occur in Papua New Guinea. The organization of the shelter neighborhood can help satisfy the next need of “Love and Belonging”. If the shelters are organized in a manner that promotes community, such as small concentric rings, then the residents are more likely to feel a sense of belonging. Past this point, it is difficult for the shelters to provide any help towards the “Self-Esteem” and “Self-Actualization” needs on the Hierarchy. However, if the citizens feel more of a sense of community with the neighborhood, it is likely that they will have higher self-esteem which will allow them to focus on self-actualization.

The shelter itself is one large communal room, so this promotes more a sense of belonging within one’s own family. This communal style home promotes a healthier, more social lifestyle with family and friends. Additionally, many of the homes in Papua New Guinea are already organized in this manner, so the shelters will not be much of a culture shock to its residents. The organization of the shelter neighborhood into groupings also promotes a social lifestyle. With this arrangement, six or seven homes
have a communal area to gather and talk. Again, this enhances the sense of belonging one will have within his or her community, as everyone is constantly surrounded by neighbors.

**Considerations for Overall System/Camp:**

Because the house is made up of three individual layers of identical pieces, transportation of the pieces would be much easier. Assembly would also be easy, knowing that each piece is just like the next, there is little room for error when it comes to constructing this house. Another point to bring up is the ability for damaged pieces to be replaced. Pieces are all similar to one another so if one piece becomes broken or heavily damaged it could be easily replaced by another one at a low affordable cost.

Due to the almost circular pattern of the house, a multitude of structures can be easily placed around one another with enough space to maneuver in between houses easily. Another possible option would be to have all the doors face one another such that they are centered around a single focal point, creating a community. Some of the houses would be facing one another as others might be facing a gap where the community opens up to let people in, as seen in Figure 13. Several groupings of these can make an even bigger community. These larger communities would promote growth and comfort across the displaced people of Papua New Guinea, allowing for economic growth and a feeling of safety. Because of the housing set up, the community can open up markets and other various economical firms that can help benefit the nation as a whole. Also, resources are not going to have to be transported to individual house but just to the local market where a short walk can get a family all that they need for the week.

![Figure 14: Design for multi house community.](image)

**Re-design Ideas/Thoughts and Conclusion:**

If a group was to take over Project X right now and redesign Prototype 2, more accurate and different kinds of testing would be encouraged. One type of test that could be implemented is a reliable “Earthquake Test”, which would measure the shelter’s durability under high amounts of stress from shaking. It would also be important to redesign the weaker points on prototype two, such as the points of pivot between each panel that the design for the housing unit had. Additionally, a different type of material would be encouraged as opposed to using cardboard for everything except the concentric ring. Using foam board in place of cardboard would have helped with sturdiness and durability on a lot of the testing...
that went through the first prototype. Some different tests, such as water testing and wind testing could be implemented to ensure that the house is waterproof against elements, such as rain and floods, and windproof against strong winds, such as hurricanes and tsunamis.

Additionally, it would be ideal for the materials that the shelters are constructed from to be locally manufactured and produced. This would lower the total cost of each shelter as well as provide easy access to those in desperate need of immediate repair.

As a whole, the group came to find that this housing unit would be very useful in the earth shaken parts of Papua New Guinea. However, small adjustments would have to be made in order to ensure for the complete wants and needs of the inhabitants of Papua New Guinea. The group decided that talking to an actual inhabitant of Papua New Guinea who has been faced with an earthquake and lived in fear would benefit the shelter greatly, because knowing what the customer wants and what he or she needs is more important than what the group thinks is needed.

The lack of a decent shelter to serve the many displaced people of Papua New Guinea is concerning. Given that the country is hit by an earthquake daily, the integrity of the current living structures is always in question if the homes are not under constant restoration. The primary goal of this project was to design a shelter that provides a location for persons displaced by those earthquakes for at least ten years.

By employing the engineering design process, the Tune Squad was able to bring an idea to life and then provide improvements. First, research on the location in question, Papua New Guinea, was required. All information is important, from the culture, to the natural resources available. Brainstorming came next, in which many ideas were jotted down, with the best one being selected. After determining all of the measurements to the design, the shelter was brought to life through a prototype. To test its application in the real world, this prototype was put through a number of tests. It was then evaluated and redesigned with any improvements added. Yet the process did not stop there. The team evaluated the cost of the new, improved design for the real scale model. Additionally, the organization of the shelter neighborhoods was discussed, as this can help improve morale within the communities. Furthermore, Maslow’s Hierarchy of Needs served as an important factor in the design process, to ensure that the residents are comfortable, happy, and safe.

Certainly no engineering feat can be described as “simple”. But the complexity behind what actually goes into completing an engineering task can only be seen on a first hand account. Even theoretically designing a shelter to be used in Papua New Guinea was a taxing process. Actually implementing the shelter in reality would be immensely more so. Design Project 1 certainly gave a taste of what it is like to be an engineer.
Works Cited


