Problem Statement

Without proper tools, equipment, or training, it can be very difficult for a team of workers to lay out a well aligned and level grid, for the construction of another structure, in this case, a greenhouse. The main objective of the Design for Emerging Markets project was to determine an efficient method to create an accurate grid of specific dimensions, with inexpensive equipment, and under a time allotment. Also, this design project was to be conducted in Sierra Leone, so the social, economic, political, and environmental factors of the area had to factored
into the planning of the project, and how the physical design was to be executed. Some of these factors include the potential seizure of the design by local governments, for example, which means that the project must be designed to perform only its designed purpose, and will be environmentally benign. Another significant aspect that has affected the way the design was built was that the local workers who are to construct the grid have had little to no experience with design projects, and will not be likely to accurately set up the final prototype into the ground.

Concept Development Summary

Before forming ideas for the first prototype, our group members researched previous projects that had been constructed in Sierra Leone. We gathered information on the economic background of Sierra Leone to see how much money could be realistically used for the materials for the project, as well as any additional costs for future maintenance and repair. We found that Sierra Leone is destitute, and in order to accommodate for the civilians, some alterations had to be made to our design. We chose to use materials available only on site, such as warped wood and string, as well as other equipment in our ten dollar budget.

Further research from our group led us to the fact that Sierra Leone has had a recent history of civil conflict, with many revolutionary groups harming civilians. To ensure for a successful project, we would need for the surrounding area to be not interfered with, and the safety of the workers would be of highest priority. Assuming the construction of the project was to uninterrupted, the design would have to be created in such a fashion as to not be able to be used against the civilians, and that it only serve purpose for its intended duty. After considering
all these factors that would affect our design, we began to form ideas and concepts for the first prototype.

For the first prototype, the desired features included an accurate 6m x 6m grid, enclosed by a level 7m x 7m area. The ground within the area of the grid needed to be level, and the corners of the grid were to be at a 90 degree angle, to ensure that a perfect square was to be formed. At the time, our group originally planned there to be only four posts in the grid: one at each corner of the square and tied together by strings. These posts and string were to be free components, and were to be placed and measured on site.

Our original design for prototype #1 included four individual wooden posts that were to be inserted into the ground manually. The pieces of string that were to be used to tie the four posts together were cut in lengths of 6 meters and 6 inches. The extra 6 inches were used as “slack” to tie around the posts. At this time, only our few early methods were being used to set up the grid. (insert pictures of prototype 1/design ideas)

Test Report Summary for Prototype #1

Pictured here is the measuring of the string to connect two of the posts together. This is a 1:3 scale, so the posts were 72 inches apart, and 79 inch lengths of string were cut to ensure that there was enough “slack” to tie around the posts.
3 inches of slack were given on either end of the rope for tying to the posts. At the end of the ruler, there is a green tick mark, noting the end of the “slack mark.” This line was to be flush with the posts, for an accurate 72 inch measurement between the posts.

Table 1: Summary of Prototype #1 Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Description of Test</th>
<th>What is Passing?</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Efficiency</td>
<td>To successfully create the grid as inexpensively as possible</td>
<td>The total cost of the construction of the grid must $10 or less</td>
<td>Total Cost = $4.75 (horizontal/vertical level)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Length of every section of the grid is to be as accurate as possible</td>
<td>Grid measurements must be precise to the nearest 3mm</td>
<td>Grid measurements were ~2mm off</td>
</tr>
<tr>
<td>Time Efficiency</td>
<td>To successfully create the grid efficiently.</td>
<td>Grid must be completely set up 10 minutes or less.</td>
<td>Successful completion in exactly 10 minutes</td>
</tr>
<tr>
<td>Use of Resources</td>
<td>To maximize the utility of all the resources available</td>
<td>Grid must be built with only resources available at site</td>
<td>Only allotted materials were used for construction</td>
</tr>
<tr>
<td>Use of Angles</td>
<td>Angles can be used to ensure more accurate measurements and cut down on time</td>
<td>Angles must be accurate to nearest half degree</td>
<td>Angles were ~0.2 degrees off.</td>
</tr>
</tbody>
</table>
To organize a method of testing our prototype #1, a design matrix pictured above was used to test different sets of criteria, to see if the prototype meets the requirements. These criterion are unweighted, which means that no one test was prioritized over the other, and the results of all tests of the design matrix are equally considered. The first test was cost efficiency. In order to succeed in cost efficiency, our group had to construct the grid using no more than ten dollars in materials. The wooden posts and rope were allotted to us for free, so the money was spent on a vertical and horizontal level, and a protractor. This totaled exactly ten dollars, so prototype #1 was considered cost efficient.

The second test criteria was the overall accuracy of the length measurements between the posts. In order for the test to pass, the measurements must have been accurate to the nearest 3mm. After laying out the grid, the highest error was ~ 2 mm off of the ideal 72 inch mark, so the original prototype passed the accuracy test. Time efficiency was also a high priority for the prototype to meet. For this test, the entire grid had to be constructed in 10 minutes or less. This was assuming that all of the building components were free and not previously tied together. The construction took exactly 10 minutes, so technically, the first prototype was time efficient, but could be altered to greatly reduce time of construction.

Another test on the design table for prototype #1 was the successful construction of the grid using only materials available at the worksite, as well as additional materials that could be purchased with a $10 budget. Available materials were warped wood, string, and metal bars. Of these, our group used only warped wood and string, as well as a purchased protractor, and a level that measures horizontally and vertically. Since no additional materials were required, our prototype passed this test. The final test for prototype #1 was the use of angles to increase
accuracy and time efficiency when building the grid. Two angles were measured: The angle of the corner posts to other corner posts, which should ideally create a 90 degree angle, as well as the corner posts diagonally across from each other on the grid, which would be 45 degrees. In order to pass, the measurements must have been accurate to the nearest 0.5 degrees, and the most inaccurate measurement was ~ 0.2 degrees off.

Prototype #1 passed all of the initial tests in the design matrix, despite barely passing some crucial aspects of the construction, including time efficiency, and overall accuracy. All of the tests were run on an area of grass on the Penn State campus, arguably similar to the conditions of the ground of worksite in Sierra Leone. The ground was most likely more hard-packed than the ground of the worksite, but also more level. The results of these tests were used to develop new improved ideas and concepts for Prototype #2 that would further increase efficiency, accuracy, and simplicity of construction.

Concept Refinement Summary

When our group first began developing ideas for the first prototype, we brainstormed individually, during the Design Thinking Workshop, by drawing any design that came to mind onto paper. This ensured that every idea was to be recorded, and that no thoughts were to be left out of the process of deciding which ideas were to be used. We found that many more ideas were able to be pooled together when we created them individually, as brainstorming in groups often leads to group members not wishing to bring their ideas forward out of fear of rejection. After compiling all of our drawings, our group selected the designs and concepts most likely to succeed when prototype #2 was to be tested. Many of the ideas chosen were successful aspects of the original prototype, as well as potential advancements in time and efficiency with materials.
The testing of prototype #1 was very informative in regard to what ideas were successful, and which ones could be improved for the next design. Some new design concepts that were considered were new posts, preferably sharper and more durable, to replace the flimsy ones previously used. New string tying methods were formulated as well, to ensure the rope between the posts was firm, and did not loosen. A main new desired feature was the inclusion of 12 posts in the outer layer of the grid, as opposed to four, with strings tied in a similar fashion to the posts on the perimeter, and ropes tied to posts going across the grid, so that the ropes made 9 distinct sections of the grid, all equal in size, to mark where the four inner posts were to be placed when the greenhouse was to be built.

Test Report Summary for Prototype #2

Pictured to the left are 12 posts on the perimeter of the grid, this time built on a 1:4 scale of the original 6 m x 6 m area. New posts have been used, these ones larger, sharper, and more durable.

Pictured to the left is a closer picture of the grid. The white piece of styrofoam serves to make visible the intersecting lines coming across from the two inner posts from each side of the square. The intersection point is the ideal place for the four inner posts of the greenhouse grid to go.
Table 2: Summary of Prototype #2 Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Description of Test</th>
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</tr>
<tr>
<td>Accuracy</td>
<td>Length of every section of the grid is to be as accurate as possible</td>
<td>Grid measurements must be precise to the nearest 2mm</td>
<td>Grid measurements were ~1mm off</td>
</tr>
<tr>
<td>Time Efficiency</td>
<td>To successfully create the grid efficiently.</td>
<td>Grid must be completely set up 5 minutes or less.</td>
<td>Successful completion in exactly 3 minutes</td>
</tr>
<tr>
<td>Use of Resources</td>
<td>To maximize the utility of all the resources available</td>
<td>Grid must be built with only resources available at site</td>
<td>Only allotted materials were used for construction</td>
</tr>
<tr>
<td>Use of Angles</td>
<td>Angles can be used to ensure more accurate measurements and cut down on time</td>
<td>Angles must be accurate to nearest half degree</td>
<td>Angles were ~0.1 degrees off.</td>
</tr>
</tbody>
</table>

The testing of Prototype #2 was largely similar to that of Prototype #1. The individual tests were identical to the tests of Prototype #1, although time allotted was decreased from 10 minutes to 5 minutes, and length measurements had to be accurate to the nearest 2 mm. The testing criterion became more difficult to fulfill, as the prototype was completely upgraded. Prototype #1 was a loose collection of 4 thin wooden posts, and string that was left untied when the time of construction began. In prototype #2, 12 sharper wooden stakes, as well as string that was previously measured and tied to the stakes, were used. This is why the aspects of the tests are identical, yet the testing of the new prototype was much different. Prototype #2 was a completely constructed grid, in the fact that all 12 of the perimeter stakes were attached by
measured string, and only needed to be placed into the ground and have the angles of the corners measured.

Other improvements in the design of Prototype #2 included markings that were made on the stakes to determine how far each stake would be hammered into the ground. From the marking which would be coincident with the level ground, another marking would on the wooden stakes four inches above the ground. This is to ensure that the string is at the same height at all of the stakes, and minimizes time needed to level the strings and ground. Another design improvement was the notching of the wood around the markings four inches above the ground, to allow for the string to be wrapped around them. This made tying the strings around the posts much simpler, and preventing the string from slipping up and down the surface. In order to maximize accuracy with the length of the string between all of the posts, the mark on the string, as previously elaborated in prototype #1, was positioned flush with the surface of the wooden stake, so that the string was forced to be tied in such a method that all of the slack was used, and no more.

The most significant difference between the testing of Prototype #1 and Prototype #2 was the physical state of the design before the tests were run on the construction of the grid. Although some alterations were made to improve the quality of the design, such as adding more posts to the perimeter, as well as using more durable, notched, and labeled stakes, having the materials in one completed tool, rendered the layout of the grid to be extremely time efficient, and much more accurate than the first prototype. Also, the most important advantage of the assembled Prototype #2, is that the strings will already be accurately tied to the posts, and the local workers in Sierra Leone will only need to layout the grid, and hammer the stakes into the
ground, without losing accuracy. Having Prototype #2 completely assembled before layout of
the grid eliminates any technicalities of measurement, and minimizes the possibilities for a
flawed method of laying out and hammering in the stakes.

Cost Analysis

Cost effectiveness and efficiency was a central focus for the formation of both prototypes
and the final product. The target country, Sierra Leone, has around a $1,334 yearly per capita
income and is considered one of the most impoverished countries in the world. To combat the
problem of limited resources, the gridding method had to meet the necessary requirements in an
affordable manner to ensure that the average citizen could have access to a greenhouse and
benefit from it. Our team devised a method that successfully accomplishes this task by creating a
kit that costs around $5, a realistic price point for the market. The materials used included 12
sharpened posts, roughly 48 feet of string, a hammer, a metal square, a protractor and a level that
was given. Although we given $10 to spend on additional materials, the only necessary additions
was a hammer at a cost of only $1.50, a metal square and a protractor at a cost of $1.00 each, and
a level at $1.25. This projects our total cost at $4.75, which is $5.25 under the spending limit. By
limiting spending, the greenhouse is more accessible and therefore more successfully
accomplishes its intended goal. In projects such as these, accessibility is fundamental in making
the product impactful and beneficial to consumers. Although cost was sacrificed, function was
not. With the materials bought, the grid can be effectively set up in the necessary time
constraints. Instead of buying more materials to make the process easier, our team used the
method to our advantage. The method focuses on measurement and math, as opposed to
alternative methods that may focus on additional materials. Overall, a conservative approach was
the most ideal approach to satisfy the necessary requirements and suit the target market of Sierra Leone.

User Guide

Greenhouse Plotting Instructions (assuming prototype is in loose components)

Pictorially Represented in Order to Avoid the Hardships of Language

Paul D’Antonio, John Carl, Kenny Dundorf, Sean Mileski
Greenhouse Grid Construction Process (assuming prototype is in loose components)

Step 1: Open packaging, make sure you have all tools
Step 2: String out stakes
Step 3: Lay stakes in square grid by pulling out stakes
Step 4: Check with square tool
Step 5: Check levelness
Step 6: Securely hammer in outside stakes
Step 7: Measure out and stake outside grid for purpose of creating the inside of the plot
Step 8: Cross with string and lay mid stakes at intersections of string
Step 9: Complete.

Greenhouse Grid Construction Process (assuming prototype is already built)

Step 1: Open packaging of 12 stakes attached with string
Step 2: Lay stakes in square grid by pulling out stakes
Step 3: Check with square tool for proper 90 degree angle at corners
Step 4: Check levelness
Step 5: Securely hammer in outside stakes
Step 6: Find the 4 points of intersection of string on the inner section of the grid
Step 7: Hammer inside stakes at points of string intersection
Re-design Ideas/Thoughts

Although the method devised would work fairly well in real world scenarios, improvements can always be made in order to advance the effectiveness of the product. Quantitative measurements such as time, cost, and accuracy could always be improved to maximize efficiency. If our team were to redesign our final product, we would start with the weakest points such as cost. Although the cost of $4.75 successfully met the needs of the people, a more affordable variant could become even more effective, as long as additional requirements are not sacrificed. A way that we could improve the cost management of the method could be to eliminate the use of a metal square and protractor. By using the pythagorean theorem, we could hypothetically measure the known diagonal and make adjustments if needed so that the diagonal is the correct measurement. Although this would slightly increase time by adding a step, it would eliminate a cost of $2.00, making the project total of only $2.75. This difference could be huge for an impoverished country such as Sierra Leone because it would further promote accessibility. Using this idea, accuracy will not be compromised and the usage of resources would be less. Aside from the cost, additional tweaks could be made to ensure that time is conserved and maximized. To accomplish an improvement, our team could prefabricate the grid so that all string is attached to all necessary posts, as opposed to only some. This would allow an individual to only need to hammer in the posts, measure the correct lengths, and level the ground. This tweak would most likely make a minor difference in timing, but could improve the difficulty of the process. The easier the process is, the more productive it will be.