The Tire Trough

West Works

EDSGN 100 Section 20

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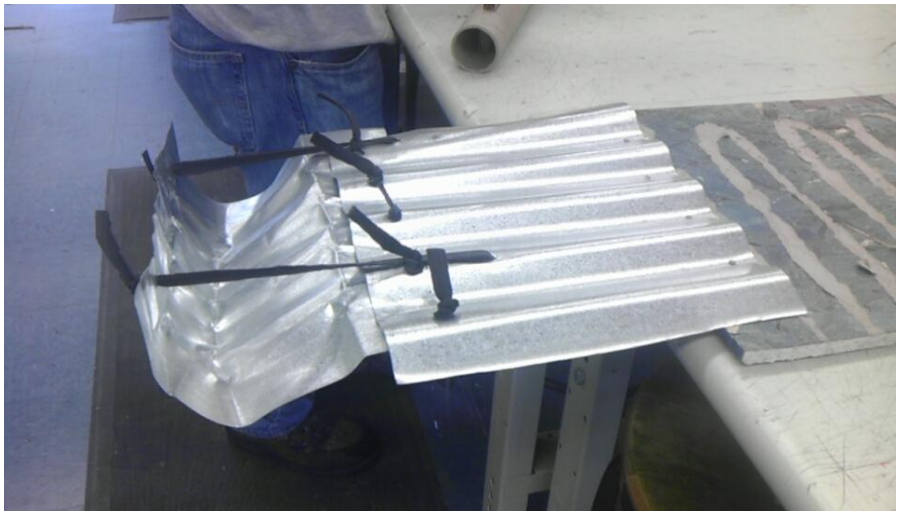

Prototype #2

Section 2: Problem Statement

Many Kenyan homeowners do not have an efficient way to collect and channel rainwater. Therefore, they need a solution that costs less than $1.00 per meter and can easily and safely attach to a corrugated steel roof.

Section 3: Concept Development

http://www.boulderkisumu.org/320px-Kenya-relief-map-towns%20Kisumu%20highlight.jpg

We began our research by first choosing a location to support with our gutter system. Upon researching many Kenyan cities, we decided on a location known as the city of Kisumu. This region is located in the Nyanza Province between the Great Rift Valley and the Kenya Highlands. The location we chose is a prominent region for agriculture and steady rainfall during two rain seasons: a long season starting in March/April and ending in May/June and a short season from October to November/December where average annual rainfall ranges from 1,740 mm (70 in) to 1,940 mm (80 in). To our surprise we found that the population of Nyanza has had a history of difficulty with regards to water access and distribution. While water itself is abundant, access is very limited.

While researching the climate of the city of Kisumu, we also learned much about the society and culture of the region. The population is made up of 22% Kikuyu, 14% Luhya, 13% Luo, 12% Kalenjin, 11% Kamba, 6% Kisii, 6% Meru, 15% other African, 1% non-African and a majority of the population practicing the Protestant religion and subscribing to a republican political view point.

After researching the desired location and associated details, we compiled ideas to decide on the desired features for our initial rainwater gutter prototype. The following features were decided upon stating that the gutter system must have: be able to attach to any length of roof overhang, be easily repairable, prevent water from running up the backside of the roof, utilize local materials, direct water to a holding tank, be made of durable materials, install with simple and readily available tools, and finally, it must have a simple design. We then complied the previously mentioned list of criteria into a table known as an Analytic Hierarchy Process (AHP).

	Available on any overhand length	Easily repairable	Water doesn't run up backside of roof	Use local materials	Can direct water to holding tank	Durable materials	Install with simple available tools	Simple design	Total	Weight
Available on any overhand length	1.00	0.33	0.17	0.17	0.11	0.25	0.33	1.00	3.36	0.03
Easily repairable	3.00	1.00	0.33	1.00	0.11	1.00	1.00	2.00	9.44	0.07
Water doesn't run up backside of roof	6.00	3.00	1.00	5.00	0.33	4.00	6.00	5.00	30.33	0.23
Use local materials	6.00	1.00	0.20	1.00	0.14	1.00	2.00	3.00	11.34	0.09
Can direct water to holding tank	9.00	9.00	3.00	7.00	1.00	9.00	9.00	9.00	56	0.42
Durable materials	4.00	1.00	0.25	1.00	0.11	1.00	1.00	1.00	9.36	0.07
Install with simple available tools	3.00	1.00	0.17	0.50	0.11	1.00	1.00	1.00	7.78	0.06
Simple design	1.00	0.50	0.20	0.33	0.11	1.00	1.00	1.00	5.14	0.04
								Grand total	132.75	

Table 1: AHP matrix for user needs to be met in design prototype #1

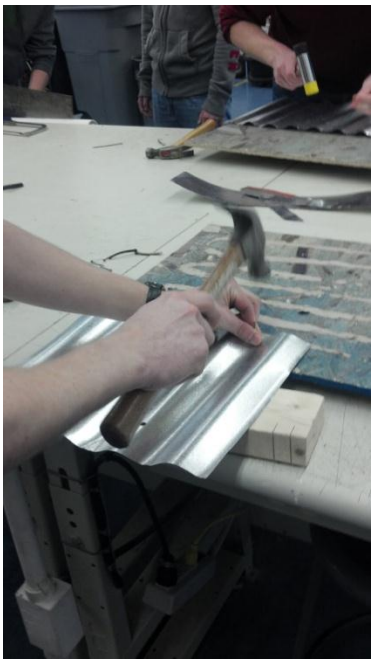

Figure 1: A model of a typical Kenyan roof is constructed to attach the gutter to.

Figure 2: A hammer is used to try to remove the hills and valleys from the corrugated steel.

Figure 3: A vise is used to put bends in the gutter for shaping.

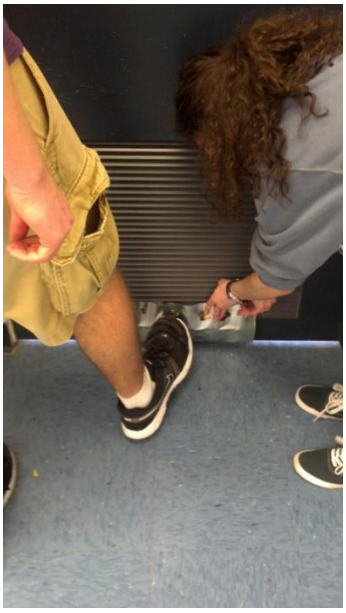

Figure 4: A door is used to bend the gutter in the center.

Figure 5: A pick and rubber mallet were used to create attachment holes for the gutter.

Figure 6: Pieces of bicycle tire were used to attach the gutter to the roof.

Figure 7: The gutter was attached at the hills of the corrugated steel.

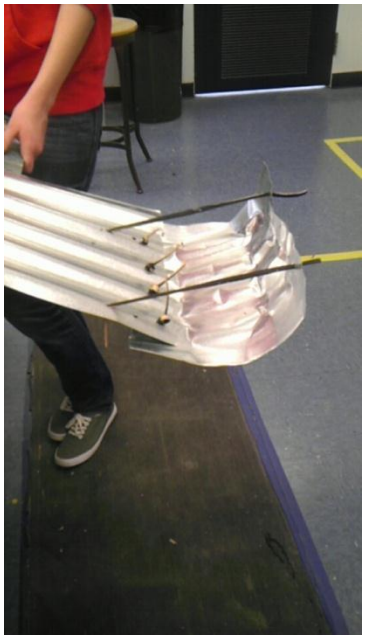

Figure 8: Tires strips were also used to hold the opposite side of the gutter up.

Figure 9: During testing water ended up running up the backside of the gutter.

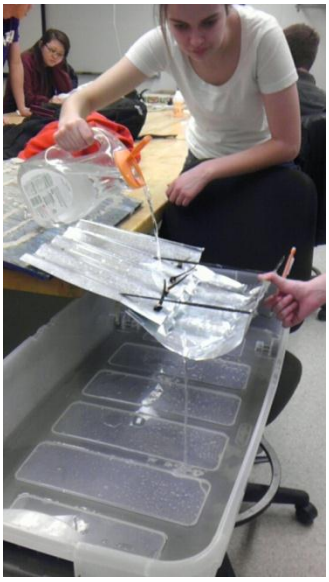

Figure10: When held down water didn't run up the backside of the gutter.

The project began with the construction of a model roof, as seen in Figure 1, using corrugated steel and a hammer. We then began trying to bend the corrugated steel to the desired "U" shape. Figure 2 shows a hammer trying to remove the grooves, however they just pop back into place. During this process, our team quickly realized how difficult it was to shape the corrugated steel roofing material while still trying to maintain the original grooves of the metal. As seen in Figures 3 and 4, a specific device, such as a door or vice, was required to bend the sheet of metal. We also found it difficult to try to remove the grooves of in the steel in a specific area. The next step was to create the holes used for gutter attachment. Figure 5 demonstrates the process. We used a quarter inch pick and a rubber mallet to create the holes in the steel. We then cut the tire strips to be about 3/4" wide. Afterwards, we fed the tire strips through the holes (Figure 6) tying a knot to attach the gutter to the roof (Figure 7). The final prototype was then completed demonstrated by Figure 8.

Section 4: Testing Prototype #1

Our first prototype with the corrugated steel and tire stripping was very close to the final design. There were only a few small improvements made after testing our design. The first prototype consisted of a sheet of the corrugated steel bent by any means necessary until we found that a vice was the right tool to use to bend. It was bent at a nearly flat angle from the roofing then a wide rounded shape at the bottom of the gutter where the water was meant to runoff (Figure 8). Also the tire stripping was used to attach the gutter to the roofing by means of small length stripping every hill of the roofing and longer length stripping every fourth hill to hold the gutter up in strong conditions.

We learned important flaws with this design from our testing. The first thing we noticed, when water was poured over the roof and into the gutter, was that not all of the water made its way to a proper channel in the bottom of the gutter. Some water would run on the underside of the roof and rear of the gutter and drip behind. This was a problem because the main intent of the gutter was to collect as much water as possible, so this was one major problem that needed to be resolved in the second prototype design. The two factors that caused the water runback problem were the small bend in the back of the gutter and the tire stripping that was meant to keep the gutter from dropping too far down, was in fact providing too much tension and keeping it too far up.

One small extra concern that we observed during these tests was that the water was not channeling down the gutter in one thin path. Rather it would run along a four inch wide path off the edge of the gutter, making water gathering unnecessarily more difficult and less efficient. So, from the first prototype, we had learned that the two design changes needed with the shape of the gutter due to its lack of proper water runoff and water falling on the back of the gutter.

Section 5: Design Refinement and Testing Prototype #2

After completing the first tests of prototype #1, we established two new design matrices for the gutter based off of the first prototype's two design failures. Both of these matrices were

features we felt were most important and would benefit the design, along with solving the issues encountered from the first tests. Our first design failure was that some of the water ran up the backside of the roof, so not all of the rainwater was being properly collected and channel. As a team, we formulated three design concepts that would solve the issue. Each concept was then graded on a 1-5 scale on how well it met the gutter constraints. Some of the constraints included easily repairable, use of local materials, etc. The design matrix can be seen below in Figure 13. Our first design concept consisted of reducing tension in the tire strips, which would ultimately let the gutter hang lower and catch any water running underneath. Our second design concept included using wires, a new method of gutter attachment from the tires, to see if there was any change in the flow of the water running on the backside of the roof. The third design concept consisted of a blocked wedge that would fit between the bottom of the roof and the gutter, acting as stop gap for water running up the backside. After rating each design concept, design concept number three's weight score of 4.95 (calculated by multiplying the 1-5 scale by the AHP weight) beat out design concept number one (score of 4.91) and design concept number two (score of 4.47). Ultimately, none of these concepts were used in the final prototype, as one long tire strip was used to fasten the gutter to the roof while holding the gutter tightly to the underside of the roof to stop the water from running up the backside.

Our second design failure focused in prototype #1 was the shape of the gutter. The design matrix can be seen below in Figure 14. We wanted to have the most efficient shape that would successfully channel all of the rainwater. Our first concept was a U-shaped gutter, the second concept being a more shallow U-shaped design, and our third design consisted of a V-shaped gutter. The V-shaped gutter received the most points with 4.91, just beating the U-shaped gutter at 4.9 points and the shallow U-shape at 4.85 points. We felt as a team that centrally locating the water to one point in the valley of the V-shape would be most effective when collecting the water. We stuck with this design concept in prototype #2, and it proved to be effective.

Once our new design concepts were established and we completed construction of prototype #2. The final sketch can be seen in Figure 11 and the final project (prototype #2) can be seen in Figure 12. Now it was time to test. We first tested prototype number one's design failure, which involved the water running up the backside of the roof, on prototype #2 with the change in design. We sat a jug filled with 2.26 liters (76.5 oz) of water directly onto the gutter, to emulate how much water weight the gutter can hold. The gutter was able to hold all 2.26 liters. This test proved to us that the amount of water nature could produce does not surpass the amount tested. Thus, our gutter will be able to hold any amount of water weight that nature can produce. We noticed that whenever a heavy weight is applied the gutter, it will droop downwards and the tension in the tire strips will increase, but when the weight is taken off, the gutter returns to its original position. Because the shape of the gutter and orientation to the roof did not deform, we considered the test and our tire strip design to be a success.

We then continued our testing by pouring a half gallon of water on the roof for 25 seconds. We noticed that no water ran up the bottom side of the roof, and that the gutter was collecting all of the half gallon of water that we poured on the roof. Performing the test again,

and pouring the water at the same rate from the first test, we were also able to conclude that no water spilled over the edge of the V-shaped gutter. This test was also able to show that the V-shape gutter was capable of collecting and channeling all of the rainwater.

We performed one final weight test on the gutter itself by placing three bags of sand on the gutter for 15 seconds. The three sandbags together weighed approximately 2.258 Kg. Similar to the water jug test, we noticed that the gutter slightly droops when a weight is applied to the gutter, but the returns to its original shape due to the constant tension applied by the tire strips. We concluded as a group that no direct downward constant force applied by any type of weather or naturally object (strong winds, downpour rain, leaves, twigs, etc.) would cause the gutter to break off from roof.

All of our tests were able to show us that our two design failures were addressed in prototype #2. We were able to design and construct a gutter that was cost effective, capable of channeling 100% of the rainwater to its desired location, easily attachable to the roof via the bike tire strips, and proved to be durable against any water weight or force from nature.

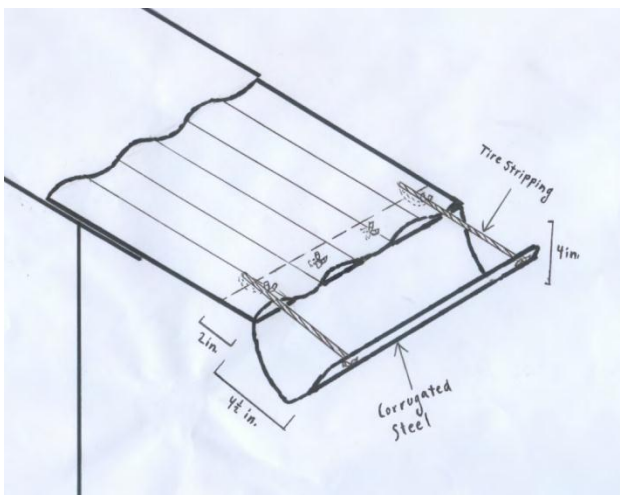

Figure 11: The final sketch for prototype #2.

Figure 12: The final design for prototype #2.

DEM Project Feb. 15, 2013 Prototype #2 Concept Selection Matrix

Design Failure needing work: Water runs back up underside of roof

Design Constaint [C] or Feature [F]	AHP weight	*Score 1-5 Design Concept #1: Reduce tension in tire stripes	Weighted Score	*Score 1-5 Design Concept #2: Change tires to wire)	Weighted Score	*Score 1-5 Design Concept #3: Add wedge behind gutter underneath roof	Weighted Score
Attachable on any over length (F)	.24	5	1.2	5	1.2	5	1.2
Easily repairable (F)	.12	4	.48	3	.36	5	.6
Water doesn't run on backside of roof (F)	.04	5	.2	5	.2	5	.2
Use local materials (F)	.12	5	.6	3	.36	5	.6
Can direct water into holding tank (F)	.01	5	.05	5	.05	5	.05
Durable materials (F)	.13	5	.65	5	.65	5	.65
Install with simple tools (F)	.16	5	.8	5	.8	5	.8
Simple design (F)	.17	5	.85	5	.85	5	.85
Cost must be under $1/m (C)							
		Total:	4.91	Total:	4.47	Total:	4.95

* Score = 1: design concept fails to meet this feature or contraint
Score = 5: design concept meets this feature or constraint very well

Figure 13: A design matrix was created to find a solution for water running up the underside of the roof.

DEM Project Feb. 15, 2013 Prototype #2 Concept Selection Matrix

Design Failure needing work: Shape of Gutter

Design Constaint [C] or Feature [F]	AHP weight	*Score 1-5 Design Concept #1: U-Shaped	Weighted Score	*Score 1-5 Design Concept #2: Shallow U-shape	Weighted Score	*Score 1-5 Design Concept #3: V-shape	Weighted Score
Attachable on any overhang length	.24	5	1.2	5	1.2	5	1.2
Easily repairable	.12	5	.6	5	.6	5	.6
Water doesn't run on backside of roof	.04	4	.16	3	.12	4	.16
Use local materials	.12	5	.6	5	.6	5	.6
Can direct water to holding tank	.01	4	.04	3	.03	5	.05
Durable Materials	.13	5	.65	5	.65	5	.65
Install with simple available tools	.16	5	.8	5	.8	5	.8
Simple design	.17	5	.85	5	.85	5	.85
Cost must be under $1/meter							
		Total:	4.9	Total:	4.85	Total:	4.91

* Score = 1: design concept fails to meet this feature or contraint
Score = 5: design concept meets this feature or constraint very well

Figure 14: A design matrix was created to find a solution to change the cross-section shape of the gutter.

Section 6: Costing

Cost estimation is based on a project where 8m x8m (32 linear meters of gutter) is added to a steel roof house. Estimate of labor cost based on time to install 32 meters of gutter assuming 400 Kenyan Shillings for one day of work (10 hours per day) by a skilled crafts man. Other assumptions include the following: the gutter is pre-manufactured and the tire strips are pre-cut.

	US Dollars	**Kenyan Shillings**
Total cost of gutter material (corrugated steel 32 square meters):	$18.00	1536.30
Total cost of gutter hanging material (bike tires cut into strips):	$1.33	113.52
Total:	$19.33	1649.82
Price per 1 meter:	$0.69	58.89
Total labor:	$4.58	390.90
Total project cost:	$23.91	2040.72

The prices were based off of the database (https://sites.google.com/site/designineastafrica/) from Khanjan Mehta. The conversions were based off the conversion rate of $1 US to 85.35 KES.

Section 7: Lessons Learned

Over the course of this eight week project many lessons were learned about the rainwater gutter project, the design process, and each other and working as a team. If the project could have another prototype there would be a few things that the team would change. With any project there are also some aspects of the overall DEM activity that can be improved. Overall, the team worked well with each other and we are all happy how the final project turned out.

No matter how well a project turns out in the end, there is always room for improvement. If our team could make a third prototype there are a few design changes we would make. Overall, the shape of the gutter proved to be the most effective for collecting and channeling water. When other shapes were tested they proved to be less effective. Thus, we would keep the current shape of the gutter. However, we would research further into some of the materials the current design features. For instance, we would look into the properties of bicycle tires. The research would include how UV rays affect the rubber, the effect of high temperatures, and the lifespan of bicycle tires. With this research, it would give our team better understanding the feasibility of using bicycle tires in the gutter system. If the research proved that bicycle tires do not hold up well in the Kenyan climate for this purpose, our team would have to find a new method of attachment. The team could also run a few tests of our own to learn about the properties of bicycle tires. To look at the effects of UV rays, we could utilize tanning beds. The lamps in tanning beds emit UV rays. The tanning beds can simulate the direct exposure of the sun rays onto the tires. Tanning beds also get very hot. The temperatures are very accurate to the

temperatures in Kenya. For prototype three, our team would not change the design of the gutter, but rather would make sure that the materials being used would work in the actual situation not just in the design lab.

The team worked very well with each other and had almost no problems. As a team we were very good about listening to each other's ideas. No individual person took complete control of the group. When one person had an idea, the rest of the team stopped and listened to the idea fully. Then collectively as a group we discussed the idea. As more ideas were given the more the team compromised. We were able to successfully combine each other's ideas into a final product. As a team we were able to communicate with each other very well. If someone was going to be missing class, they let the rest of the team members know at least one class in advance. However, one of the things that did not go very well was attendance. Like previously stated, the team was aware when a member was going to be absent. But, this caused issues when members were absent on testing days. The rest of the members informed the missing members the results. But it was difficult when it came time to write the report. As much as you can explain to a person the results, it does make it difficult when you are not there to see the tests first hand. Thus the absent members had a difficult time contributing to the written report. This was the only issue in the team dynamics. For the most part we all took on equal roles. The time put into each section of the project was equal. Two members did the majority of the research and the other two members did the majority of the construction and testing. If the roles had to be changed, the roles could be more equal. All the team members could contribute to the research, construction, and testing.

The DEM activity could be improved in a few ways. One suggestion would be to bring in students who had been in Kenya before to give their insights into the availability of materials, tools, and the relative importance of user needs and design features. Someone can get a basic understanding on another country through research, but it is presented in a neutral tone. It is hard for someone living in a wealthy country to visualize the living conditions of third world countries. Someone who has seen both could give better comparisons for us to understand. Another suggestion would be to offer a project that the students have some idea about. Most students chose to work on the rainwater gutter project over the greenhouse glazing project. The reason our group chose the gutter project was because we have had some experience with rain gutters. Greenhouse glazing is a completely foreign idea to most people and that could deter people from choosing that project. So if the instructors want a more equal spread of project choice, offering another DEM project is suggested.