DEM Project Option 2:  
Greenhouse Joint Protection  
“Jointment”

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Team #1, Submitted to: Professor Susan Beyerle, March 6, 2015

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Mission Statement

The Mavuuno Company and the Penn State HESE Program generously offer greenhouses to communities in countries including Kenya, Rwanda, Sierra Leone, and Mozambique. However, one significant issue that has presented itself is that several factors cause the glaze, the material that covers and allows the greenhouse to facilitate plant growth, to tear. When the glazing tears, it hinders the performance of the greenhouse and renders its purpose moot. The Black Mambas’ product, named Jointment, is a durable, effective, and cost efficient buffer that will supplement the major joints of the greenhouse. This product will reduce the likelihood of the greenhouse glaze from tearing at each of the joints, which are located at the apex of the greenhouse. This joint repair product will in turn increase the sustainability and longevity of the greenhouse. The main goals for the product include, but are not limited to, helping to increase the crop yield in Mozambique from a half year to a full year, creating a universal product that can conform to any greenhouse joint configuration, allowing availability of the greenhouse and the joint buffer solution to tribes and villages located in Mozambique and throughout Africa within the next year, and for each buffer to cost less than $2.00 per joint. However, with an effective design, each joint could possibly cost less than $1.00 per joint. The Black Mambas also intend to include multiple joint reinforcements with each greenhouse kit, depending on how many will minimize the tearing of the glazing and also how many can be provided based on the financial constraints. The primary market for the product is focused towards the local farmers of Mozambique with the secondary market targeting the rest of the citizens of Mozambique, as well as the neighboring countries in Africa. For the design of the product, the team assumes that the local farmers will be accepting of the joint repair due to its marginal benefits. Also, it is assumed that the carpenters in Mozambique have basic tools such as box cutters and nails that can be used to apply or alter the Jointment, if necessary. Lastly, the stakeholders
of the design include HESE students and the HESE program, the government of Mozambique, the Mavuuno Company, and the farmers, tribespeople and villagers, and laborers of Mozambique.

Concept Development - Prototype #1

Contextual Summary

When taking on the challenge of helping projects that occur abroad, research is a critical key to success. Therefore, general background research was conducted for Mozambique. To begin, Mozambique is a country that is located in South East Africa, which has a tropical climate with two seasons; a wet climate that spans from October to March, and a dry climate from April to September. Cyclones are common during the wet climate (1). Furthermore, Mozambique is a low-lying coastal area that has areas suffering from somewhat arid landscapes (2). The half of the year that is dry and arid does not allow for substantial crop growth. During the wet half of the year, the cyclones are environmentally harsh, and also harsh on the materials of the greenhouses, especially the glazing covering the joints. This leads to the necessity of a strong, durable greenhouse that can provide continual crop growth year round.

Along with climate and weather ordeals, Mozambique has also had to deal with social, political, and civil issues since becoming the independent People’s Republic of Mozambique in 1975. Two years after gaining independence from Portuguese rule, Mozambique entered a civil war, which lasted until 1992 (3). While they have maintained a rather stable republic since the elections of 1994 (1), the civil strife had a major impact on several key component of Mozambique.

The civil issues caused education and economic standards to suffer. While the expansion of the school system has caused 100% of children to be enrolled in primary education, this statistic is tainted
by other factors. Due to the rapid expansion, a lack of teachers caused the existing teachers to be overworked. With poor teachers, completion rate is severely low. A staggeringly large portion of the population remain truly uneducated (4). Regarding economics, the country is considered to be a low-income society with $610 per person per year (5). While the Mozambicans get by, their financial situation does not allow them to access resources or live with ease.

While the design and implementation of greenhouses throughout Africa so far has been shockingly effective, there are still issues that need to be refined. To cope with the weather and climate, a joint buffer like Jointment needs to be provided with the greenhouse kits so that the greenhouse can withstand the rough natural elements. For such a product, the installation instructions need to be simple and easily understood by an undereducated person due to the poor education status in Mozambique. Pictorial instruction could be the most effective method of presenting the instructions. Furthermore, the joint solution needs to be cost efficient so that it can be integrated and accepted into the culture of Mozambique without restriction. By designing a product within the constraints of Mozambican culture, and facilitating the deliverance and construction of greenhouses including this product, the country of Mozambique can grow to become healthier, more economically and politically stable, and more prosperous.

Prototype #1 Criteria

When designing the first prototype, the major features that needed to be present were cost efficiency, speed of assembly, ease of use, and durability. Prototype #1 was applying spray foam from a can of insulation foam to each joint, thoroughly covering a protecting the joint. Each joint supplement needed to meet a financial constraint of under $2.00. This is one of the more important criterias for the
product, since if it could not meet the expectation of less than $2.00 per joint, then the design would likely be rejected by the Penn State HESE Program. This would result in no solution being delivered to Africa, which would cause the people of Mozambique to further suffer from food poverty. Next, the Prototype #1 needed to be able to be applied quickly, in a matter of under 15 minutes, which would allow the carpenters to continue with the completion of the greenhouse construction. The carpenters already have to spend several hours to create the layout for the joint, so any additional time required to assemble the joint is a hindrance to the build. Prototype #1 also needed to be easy to assembly. Since most of the population in Mozambique is undereducated, the design for the joint cover could not be complex or extravagant. It needed to be simplistic, and almost self-explanatory. However, instruction would still be provided. The ease of use can be directly correlated to the time of assembly. The longer the application takes, the more complex and difficult it is to use. The most important criteria for Prototype #1 is that it is a durable solution to the joint problem. If Jointment were used in the environment of Mozambique, it would have to withstand over five years (the lifespan of the greenhouse) of direct exposure to temperatures over 70 degrees Celsius, continuous moisture within the greenhouse, and the wind from cyclones. If the product failed within five years, the glazing would have to be removed and a replacement joint repair would have to be applied to the joints to avoid destruction of the glazing. This process is to be avoided at all costs.

Initial Sketches
Joint

1. Additional Materials at Joint
   - If the fastening of the glaze and the joint connections remained the same, additional material could be added to the problem areas.

   ![Diagram]
   - By adding additional material, the area would be more robust and resistant to tears.

   ![Diagram]
   - The technique of fastening
     - Instead of nails, zip ties can be used to fasten the joint. This reduces weight and price, and increases durability.

   ![Diagram]

   2. Technique of Fastening
     - Regardless of what the material is fastened, it should be fastened so that the glazing doesn’t put all of its weight on the joint. Glue should create a “bubble” between the wood and glaze.
#4. Foam Barrier
Foam could be applied to the rough spots of the weld and joint. This would "float" the material from the wood, dramatically reducing tearing.

#5. Shaving/Sanding/Grinding
- Either a cheap tool to remove rough edges or sandpaper could be used to smooth the wood.

#6. Flat Top Joint
- Using a saw, the carpenter could remove the pointed top of the joint, creating a flat surface. This will increase the surface area that the gusset rests on, reducing the probability of tearing.

1 These images show some of the initial brainstorming ideas for the joint. Other ideas were created, like in the scoring matrix below, but they came later in the engineering design process and are not included.
The two images above, which derive from a single table (the top picture being the first half, the bottom picture being the second half,) are the concept scoring matrix that was used to compare and rank all of the concepts being debated for testing. Concept 1 is “Spray on Foam,” which is the insulation foam that comes in a can. It is resistant to heat and moisture due to its insulative properties. Concept 2

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2 Since seven concepts and eleven criteria were involved, the team elected to skip the screening matrix and choose the preferred, more detailed scoring matrix.
is “Sheet Foam,” which is a material similar to swimming pool noodles. It comes in sheets and is easy to cut and shape to any configuration, allowing it to work on any joint. Concept 3 is simply “Fleece Cloth,” which would be cut into strips several feet long and wrapped around the joint and the surrounding wood. Concept 4 is “Seat Cushioning.” The material found in any old seat cushion is very compressible and conforms to any inconsistency or protrusion in the joints. Concept 5 is “Extra Glazing.” This concept requires taking additional pieces of glazing them and layering them to the main glaze with glue where the joints will be located. The extra material could increase the tensile strength of the glaze by over 150%. Concept 6 is “Rope Binding,” which involves wrapping rope or parachute cord around the joint, allowing full coverage and easy attachment to the greenhouse. Concept 7 is “Filing Tools/Sandpaper.” This concept required a simple, cheap tool that was purposed to file or grind away the rough edges and protrusions of the joint. If the tool did not exist, the next best alternative was sandpaper, which could meet the same requirement.

Prototype #1 Testing
For Test 1, the spray foam passed the “wind” test because absolutely no marks, stretching, or tears occurred when “flapping” the glaze over the repaired joint. Compared to the control joint, the

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3 This is a table of testing information for Prototype #1. It includes user needs, a description on each test, how the test passes and fails, and what materials are needed for each test.
spray foam performed way better, since the control joint caused the glazing to tearing only after about twenty seconds of testing.

For Test 2, the spray foam passed the tension test because very little stretching occurred. The interesting part was that the spray foam distributed the force on the glazing over a larger area compared

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\[4\] This is the destruction of the glazing after only a few seconds of wind testing. This is one critical reason why the joint repair is needed.
to the control joint. Therefore, it seems that over a long period of time that the weight can be managed well by the spray foam.

For Test 3, the spray foam passed the heat test, because after 15 minutes of continual heating, the spray foam remained intact and stayed adhered to the joint. Also, there were no bad reactions

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5 These images show the comparison of the tension test. With the control joint on the left, it is evident that tearing can occur. You can see in the right image that the spray foam efficiently distributes the tension, causing nearly no stretching.
between the glazing and the spray foam after heating. One issue that occurred was that the foam became slightly squishy, and a hole appeared because of this. If this occurred on an actual greenhouse, it could lead to the foam diminishing over time.

For Test 4, the spray foam passed the moisture test because it is naturally repellant of water. No water was absorbed into the foam. The foam remained intact and it stayed adhered to the joint. However, if water entered the hole from Test 3, issues could arise, like weakening of the wood and

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6 By simply pressing a pencil to the foam after heating it, it is evident that the foam conformed around the pencil since it was squishy. This can lead to problems in our final design.

7 The hole that occurred in the foam is near the corner of the joint. If the glazing came into contact with it, the purpose of the foam is defeated.
weakening of the adherence. For Test 5, the joint automatically passed the adhering test, because it is self-adhering to the wood. It needs no external material to connect to the joint. This reduces the installation time.

When testing the spray foam, it had a curing period of eight hours. During this time frame, no manipulation or construction of the joint could occur. From this, it was evident that Prototype #2 needed to be fast to apply. Since the weather changes spontaneously in Mozambique, the greenhouse needs to be made as fast as possible. Wasting eight hours is not an option for the carpenters. Also, the spray foam can was expensive, and could only be used for a 15 minute time frame. After that, the remaining spray foam was not able to be used. Working under this constraint made it difficult to apply the spray evenly and fully. This lead to the need for Prototype #2 to be easy to apply and able to cover any joint possibility.

Design Refinement - Prototype #2

Prototype #2 Concept
The team realized that sheet foam was a good route because of the qualities it provided. It gave the joint the cushion which was needed in order to reduce tearing. After testing, the team concluded that the spray on foam was to not be developed further. While it did not retain water and performed okay with the wind and tension tests, the heat was a large concern for the team. Prototype #1 passed the heat test based on the predetermined guidelines, but it did manage to become somewhat weak and “squishy.” Also, it developed a slight hole when combined with water after the heat test. If this happened in the field, it could be a disaster for a greenhouse. From these results, the team decided to scrap that idea and move forward. Using the issues from Prototype #1, such as time of installation and difficulty of use, the team realized that the second design should be simplistic, straight forward, and easy to use. In moving forward, the team sought out sheet foam. The team connected the foam to that of flotation devices or pool noodle, and figured before hand that it would do well with the water test. After examining the material before installation, it was concluded that it would provide the softness factor which is a quality most important to the reduction of tearing of the glazing. It was easy to use, as well as fast to use, which are the major aspects that were considered.

Prototype #2 Sketch
Prototype #2 Photos

From left to right and top to bottom: The simple cross design of the sheet foam, the product being applied to an abstract joint with twine fastening, the final idea of attaching the sheet foam with a nail, and the design being tested for water resistance.
Product Instructions

These are the pictorial images that describe how to attach the Jointment to the joint. As shown, the carpenter must take the product and orient it with the nails in it. Then, it must be placed over the joint. Lastly, it must be nailed into the joint. The process is not difficult, but images must be provided so that the people constructing the greenhouse have some guidance as to how to use the product.

Test Conclusions for Prototype #2

Prototype #2 passed each of the tests, which are the same test as for Prototype #1. For Test 1, the simulation of wind and glazing flapping over the joint yielded no marking or imperfection in the glazing, so the design passed Test 1. For Test 2, which is high tension, there was hardly any stretching and absolutely no tearing that occurred, therefore Prototype #2 passed Test 2. For the heat test,
Prototype #2 remained intact after 15 minutes of heat exposure and withstood compression and tension after being applied with heat. For the water test, Prototype #2 did not retain any moisture and it remained intact and could withstand compression and tension after being submerged in water for five minutes. For the attachment test, different methods of installation were tested. These methods included zip ties, twine, staples, and nails. After attempting to adhere the sheet foam to the joint with each of the methods detailed above, the nails were the best option of application. Twine was very unstable and came untied very easily, zip ties were difficult to fasten, and staples and a staple gun are not included with the carpenter and would be extremely expensive.

Lessons Learned

After testing and evaluating the sheet foam design, it was obvious that there were several critical flaws. These imperfections included the method of fastening the foam to the joint, as well as the choice of materials for the design. At the DEM Showcase, it was brought to attention that the sheet foam may not be as durable as previously thought. The foam could degrade within weeks if exposed to direct heat and ultraviolet lighting, and it could become waterlogged and fragile in the moist greenhouse over an extended period of time. It was also mentioned that the method of application could be improved. The second prototype was fastened with nails that were already included in the greenhouse kit and with the carpenter, in order to reduce the addition of more materials. However, these nails have small heads, which could easily pierce through the sheet foam if not correctly used. In order to improve upon these concerns, Prototype #3 would be an improved version of Prototype #2. All of the test performed, especially for heat, moisture, and wind resistance, would be unchanged. An addition test that would be added is adherence strength to compare the effectiveness of different methods of fastening the product.
to the joint. The benefits of using the same tests is that Prototype #2 becomes the new baseline, control or standard for Prototype #3. If Prototype #3 was created, research on alternative materials similar to sheet foam, with qualities like softness, compressibility, shock absorbency, and cost efficiency would have to be done. The goal would be to find a material that is locally available in Mozambique that is also more resistant to heat and water than sheet foam. In regards to the installation, instead of using nails with small heads, the plan would be to test fastening the joint support with nails that have larger heads, such as umbrella nails. The head of this nail would act like a washer, preventing the sheet foam from sliding over and falling off of the nail.

Considering how well the design performed at the DEM Showcase, it is clear that the design went well for the team. This was due to several factors. First, the Black Mambas is a team that consists of students from several different backgrounds. Nathan is from a small high school, Adrian is from a high school with as many kids in his grade as in Nathan’s entire school, and Peeyush and Raghav are from schools located in a different country. All of the students come from distinctly diverse backgrounds, causing them to think in dramatically different ways. This allowed the Black Mambas to create several different unique ideas for the joint design in the brainstorming portion of the project. Possibly the most important aspect of the group, however, is that every member was willing to communicate their ideas to the group at large. No member was silent or shunned for their ideas.

While achieving a high level of success, the team feels that it could have most definitely done better at certain aspects of the project. The project could have been more productive if each team member was on the same page and up to speed each step of the way. This “jetlag” in work progress was caused by a lack of time management inside and outside of class time. When a team member worked outside of the classroom without informing the other members of the extra work, often one or
more members was a little out of the loop which hurt the progress of the project. To improve the time management, common work hours should have been chosen when all group members could meet outside of class to work on the project together. Also, if a member could not work with the rest, it should have been the responsibility of all members to leave no member behind when it came to the progress and status of the project.

The DEM project seemed to be a rather large success. For example, it exposed every group to the engineering design process, leading them step by step through how it works and what its purpose is. Also, the time allotted for the project was more than sufficient. Some improvements that the Black Mambas have to offer are as followed. First, the director of the HESE Program, Khanjan Mehta, should have been the person to speak on behalf of the greenhouse design, not a student involved in the HESE Program. If HESE wanted more efficient, better engineered joint solutions, Mehta should have been the person offering advice and answering questions about the project in the initial stages of the project. Also, if the workshop was open every day instead of only Sunday through Thursday, many more students would be able to use the workshop. This is because Monday through Thursday is a busy time for students when working on material in other classes. Friday and Saturday offer stress free time to simply focus on the project at hand.

Works Cited

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