Low-Cost Strider for Guatemala

A Senior Project

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By

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Stand: Standing Technologies Accommodating Numerous Disabilities

A Senior Project Developing a Low Cost Assisted Standing Device for Use in Developing Nations.

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**Statement of Disclaimer:**

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.
Abstract:

The purpose of this project was to create a strider, a type of standing rehabilitation device, for children in developing countries who have trouble walking and supporting their full body weight. The project was initially brought to us by Cal Poly professor Brian Self, who had visited a clinic in San Marcos and determined that there were children there who had difficulties with walking and were a need for a rehabilitation device. The team discussed the problem with Dr. Self, Matt Robinson (a local San Luis Obispo prosthetist), and Cal Poly physics professor Pete Schwartz, all of whom had visited San Marcos previously, the determined that the device must also use appropriate technologies so that it could be easily reproduced for a low cost in clinics and for children to use at home in developing countries. For these reasons, the team chose to create the device from bamboo held together with composite joints. After researching material availability in San Marcos and existing bamboo and composite manufacturing techniques, the group designed a triangle-based structure made of dried bamboo for maximum strength. The design was analyzed using engineering analysis for the effects of bending, buckling, impact, and more. The team next created a prototype of the device at Cal Poly and tested it for failure before journeying to Guatemala to re-create the device at the clinic. In San Marcos, the device was completely manufactured in only three days and was also tested using a healthy 11-year-old girl. The team left the completed device, as well as two harnesses, at the clinic and is currently awaiting feedback from Dr. Rojas, who is in charge of the clinic and promised to use the device when disabled children come into the clinic. Nicole will continue to make improvements to the design as well as establish communication and relationships with other clinics interested in the device in the fall.
Acknowledgments

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INTRODUCTION

The fundamental purpose of the STAND project is to improve the quality of life of children aged 4-15 with disabilities, amputations and other physical limitations at the clinic at La Casa General Hermanas Franciscanas De La Asuncion. The device was designed utilizing appropriate technology principles to allow for the device to be reproduced by other clinics and individuals in various developing nations. Our customers were patients of Dr. Bernarda Rojas from the free clinic in San Marcos. Dr. Rojas treats patients with a variety of neuromuscular disorders including the following: cerebral palsy, spinal cord injuries, amputations, and spinal muscular atrophy along with other similar disorders.

Our team of Mechanical Engineering students consisted of Nicole Cooper, Gonzalo Hernandez, and Jared Tower and we received advice from a Kinesiology student, Jessica Smith, to develop a ‘strider’ to provide an exercise and rehabilitation tool for our customers. A strider is an assisted standing device which allows the user to support varying amounts of their own body weight.

The motivation for this project was to increase the mobility of our customers (patients of Dr. Rojas). Rehabilitation in a standing position helps to improve the patients’ leg strength as well as benefits their vascular and muscular health. The device additionally aids the clinicians who assist the patients at the San Marcos clinic by giving them a rehabilitation tool that requires minimal clinician support to use. There are also social benefits as our customers are able to interact with others around them at eye level. Ultimately the STAND Strider accommodates individuals with a wide range of disabilities and can be reproduced in developing nations.

BACKGROUND

The clinic in San Marcos, Guatemala serves mainly children with neuromuscular disorders. The clinic includes a large courtyard floored with smooth concrete and a large outdoor yard where the device will be used for rehabilitation purposes. However, as the ground in the yard is bumpy and harder to traverse for patients with limited mobility, the device will be used mainly in the concrete patio. Children stay at the clinic for several weeks during their treatment where they will be able to use the device we build for the clinic, but most treatment ends when they leave. By equipping them with a device to take home after leaving the clinic they can continue rehabilitation which will continue to benefit their overall health and leg strength.

The customers who will be using our device have a wide range of orthopedic and neuromuscular disorders; thus, they will benefit from a device that will assist them in developing their strength as they exercise through standing and walking with the device. There are currently numerous assisted standing devices available to patients with orthopedic and neuromuscular disorders; however, the high price of these devices makes it impractical for people in developing nations to purchase their own. Additionally, the design and materials of the devices make it difficult to produce them in developing nations.
SPINAL MUSCULAR ATROPHY (SMA)

Spinal Muscular Atrophy (SMA) is a neuromuscular disease that impairs the body's ability to contract muscles - specifically muscles located in the torso and neck. As a result, the muscles atrophy leading to a decreased ability to sit, stand, or walk for people with SMA. Some people affected by SMA may never develop these abilities or may completely lose them.

SMA is a result of defects in the Survival Motor Neuron 1 (SMN1) gene which is responsible for encoding the SMN protein. The SMN protein is critical to the health and survival of nerve cells in the spinal cord which control muscle contractions which accounts for SMA's mobility hampering effects. Currently, one in every 6,000 to 10,000 children are born with this disease which makes it the most common rare disease. To attenuate the effects of SMA it is important for people with SMA to regularly exercise and to participate in physical therapy to build and to maintain muscle strength.

CEREBRAL PALSY

Cerebral palsy is a disorder of movement, muscle tone or posture that is caused by an injury to the immature brain by non-contagious factors, usually before birth. It causes impaired movement related to exaggerated reflexes, rigidity of the limbs, abnormal posture, involuntary movements, and unsteadiness of walking or a combination of these. The effects can vary significantly among those affected. Some people can walk while others cannot, and some show normal intellectual function while others suffer from developmental brain abnormalities. People with cerebral palsy may have difficulty swallowing and commonly have eye muscle imbalance as well. Cerebral palsy appears during infancy usually before 3 years of age and permanently affects the body but does not worsen over time.

Although cerebral palsy cannot be cured, treatment can and will often improve a child’s capabilities. The sooner treatment is initiated the better chance children will have overcoming developmental disabilities or learn new ways of overcoming their impairments. Depending on the severity of the symptoms, treatment may include physical and occupational therapy. This can include speech therapy, medication, surgery, braces and orthopedic devices such as wheelchairs and rolling walkers.

INCOMPLETE SPINAL CORD INJURY

“Spinal Cord Injury” is used to describe any spinal cord injury that is a result of trauma, not disease. Spinal cord injury is labeled as “incomplete” if it does not completely incapacitate all function of the spinal cord. This injury can have varied effects on patients, but the most common is partial paralysis. The severity of the paralysis or symptoms experienced by patients is dependent on the severity of the injury to the spine and on whether or not the nerve roots are affected by the injury. The location of the body affected by the injury is dependent on the location of the injury along the spinal cord.

Patients with paralysis due to spinal cord injury can make significant improvements within the first six months of injury and can also learn to move around with the use of assistive devices. A strider device is an effective way to initially rehabilitate and later allow for greater mobility for a spinal cord injury patient.
AMPUTATION

Amputation is the removal of part or all of an extremity and can be a treatment for many different injuries and diseases, including but not limited to severe trauma, infection, and disease. Patients who have had a limb amputated are often able to recover some use of the remaining part of the limb, which can be aided by the use of a prosthetic. A prosthetic “replaces” the missing part of the extremity and helps the user carry out functions normally performed by that limb.

A strider device would be an excellent rehabilitation and mobility aid for patients who have had an amputation and are working to regain some function of the amputated limb either with or without the help of a prosthetic. It would help them practice performing the functions of the missing extremity or get used to using their prosthesis.

GAIT TRAINER

Gait trainers are commonly used in therapy to allow the user to ambulate while still receiving support from the frame. The user interfaces with the device through an adjustable harness system which attaches to the frame and allows for variable amounts of the users weight to be supported through the frame rather than directly onto the users legs. Additionally, the harness helps to support the user's torso which is a critical feature when treating a person with SMA. Arm prompters can be attached to better position the user's body and ankle and thigh prompters can be used to keep the legs from buckling when ambulating.

Gait trainers are widely used to help people with conditions such as SMA, Cerebral Palsy and incomplete spinal injuries increase their strength and mobility. However, the high price of these trainers makes it difficult to use them in developing communities and a less expensive alternate is needed.
STRIDER 2.0

A Cal Poly senior project team developed the ‘strider’ shown here for Nathan, a five-year-old boy with SMA. While specifically developed for children with SMA, the device could be easily adapted to accommodate people with Cerebral Palsy or incomplete spinal injuries. The strider suspends the user from overhead poles by attaching to a harness worn by the user. The harness serves as both an attachment point for the user and a support for the user’s torso. A desirable feature of this strider is the suspension system built into the harness interface. The suspension allows for the amount of weight required for the user to support to be varied by raising and lowering the user to a desired height. It also serves to dampen the effects of shocks from bumps and rough terrain.

This strider is a good tool for increasing the mobility of people with various conditions but would be impractical for use in developing communities because upright poles require carbon fiber tubes which would not be available in most of these communities. Additionally, the high price and large width make using the device at a clinic in a developing country unfeasible.

SUSPENSION WALKER

Suspension walkers provide easily adjustable amounts of weight support to the user through an overhead support system. The larger frame allows for a wide range of users to be accommodated and the casters allow for easy movement. A suspension system and safety straps ensure the user’s safety while being placed into the device as well as while using the device. Additionally, the suspension walker uses a winch to adjust the user’s position. The Kaye Suspension Walker shown to the left has pivot points to allow for the system to be folded and stored easier while not in use.

Ultimately, these devices seem to allow for the most adjustability making it easy for one device to accommodate a wide range of users. However, suspension walkers such as the one shown cost around $1500.00 for the frame, suspension system, and harness which would make it difficult for a family in Guatemala to be able to afford.
HARNESS

There are many different methods currently used to move people with disabilities from one place to another. One of the most common needs for people with limited use of their legs who are undergoing rehabilitation is safe transport between a bed or a table to the device (walker, wheelchair, strider, etc.) that they will use for rehabilitation. Common methods for accomplishing this include the use of slide sheets, transfer boards or belts, slings, and hoists. While these all work to various degrees, a method that does not require an intermediate load bearing step, such as holding up the patient by one’s own strength, will be the most helpful to the clinic.

Walking harness slings are commonly used to support various amounts of weight for patients in various situations including sitting, walking, and standing. They can provide varying amounts of weight support for patients ranging from complete to very little support. This allows therapists to adjust the amount of weight supported by the user to accommodate the user’s ability to support their own weight. This adjustability is very useful as the amount of weight supported by the device can be lessened as the rehabilitation progresses and the user gains strength. These supports are often suspended from ceiling or other overhead hoists that are designed to move as the patient moves which allows the patient to feel as though he or she is walking on their own.
PROBLEM DEFINITION

The clinic in Guatemala required a device that would aid patients who need regular exercise to improve their mobility. Additionally, patients who are learning to walk with a prosthetic needed a device to provide support as they familiarize themselves with the prosthetic. The assisted standing device developed for the clinic met these needs and additionally allows the patients to spend time in a standing position. Ultimately, the device improves the quality of life of our customers.

OBJECTIVE

The team aimed to combine the most desirable features of the products listed under the background information section of this proposal into a single device. What makes this particular project unique is that the device was designed to be made using materials and manufacturing methods that are available in Guatemala. A device was manufactured for the clinic and an instructional manual was created to allow others to reproduce the device. Through the use of a quality functional deployment (QFD) matrix (see Appendix B), our customer’s desires were turned into engineering parameters which were then turned into design requirements (see Appendix A). The following points highlight the intended features of the device and Table 1 summarizes the following list.

The device was desired to:

● Allow user to be placed into a standing position and support from 0 to 100 percent of their own weight. This was a high risk quality because the success of the device depended on accommodating the user’s current strength level.

● Be able to roll or remain stationary. This was a high risk quality because while placing the user in the device it is necessary to prevent the device from rolling, but, in order to help the user develop strength or become more comfortable walking, the device needed to roll to allow for natural walking movements.

● Be easily set-up. This was a low risk quality because the device can be left set-up after initially being assembled. While it would be nice to allow for easy assembly and disassembly it is not a critical device function.

● Be lightweight. This was a high risk quality because the device may be used by patients with limited strength. If the device is too heavy, they will not be able to naturally move with the device. This will hamper their ability to build strength or practice walking.

● Be safe for the user to use. This was a high risk quality because it is extremely important that the device’s users are kept safe while in the device.
• Made inexpensively and using basic manufacturing methods. This was a high risk quality because one of the goals of the project was to allow for the device to be easily implemented at the clinic in Guatemala. The cost and manufacturing was important for this as the average income of a family in Guatemala is around $5,000 to $7,000 per year and available manufacturing methods are limited. If the device was expensive and required advanced machining techniques it would not be easily accessible to this region.

• Be adjustable for a wide range of users. This was a medium risk quality because the device was designed to be built for individual patients. However, the device is much more beneficial to the clinic if individual devices can accommodate more than one user. It needed to be able to accommodate different weights and sizes of patients.

• Be compatible with different disabilities. The device may be used for patients with SMA, Cerebral Palsy, incomplete spinal cord injuries, and amputees along with others. This was a high risk quality because if the device did not accommodate people with these conditions it would not be able to function as desired by the customer.

• Be able to fit through a doorway. Doorways in Guatemala are not as standard as in the United States. This was a medium risk quality as this device is meant to be used indoors. Therefore, it is necessary that it be able to fit through the range of doorway widths in Guatemala. After traveling to Guatemala, it was observed that the widths of doors was fairly standard in main passageways with smaller doors in more obscure areas. As the device will mostly be used in areas with easy access (main passageways) this was only a medium risk quality.

• Fit into a small volume when disassembled. This was a low risk quality as only one device needed to be transported from the US to Guatemala and it was not necessary for it to be disassembled for storage even if this would have been a nice feature for the customer.

• Be accessible from a sitting table (See Figure 4). Most of the clinics in this area use sitting tables when working with their patients. It was important that the user be able to interface with the device from a sitting table. This was a medium risk quality as a sitting table will be the primary means for the user to interface with the device but not the sole medium.

• Allow for only one additional person to place the user into the device. This was a medium risk quality as it would be acceptable for two people to be required to place the user into the device, but ideally one person would accomplish this.
Table 1. Formal Engineering Specifications

<table>
<thead>
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<th>Spec. #</th>
<th>Parameter Description</th>
<th>Requirement or Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
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<td>Max</td>
<td>H</td>
<td>A, T, S, I</td>
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</tr>
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<td>9</td>
<td>Additional People Required to Help User Into Device</td>
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<td>Max</td>
<td>M</td>
<td>T, I</td>
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<td>10</td>
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<td>11</td>
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<td>Range</td>
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<td>A, T, S, I</td>
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<td>14</td>
<td>Length from Back of Device to User Interface</td>
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</table>

**Risk Level:** High (H), Medium (M), Low (L)

**Compliance:** Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)
DESIGN PROCESS

The flowchart below illustrates the design process followed throughout our project. To initiate our project a problem had to be defined. After establishing and selecting a problem, a thorough understanding of the problem was necessary to be able to adequately address it. Background research and preparation for the project were performed to establish a solid foundational knowledge. Generation of possible ideas on how to solve our problem was next in which the ultimate goal was to come up with the best possible solution to our problem.

Next, the detail design needed to be included. This included performing the necessary analysis on the solution we decided to pursue, and, from there, creating a set of drawings. The detail design was approved by our sponsors and the materials needed to build a prototype were ordered. Once all of the materials were obtained, the prototype was built and tested. Once we verified that the device met the customer’s requirements we traveled to San Marcos, Guatemala to build a device for the clinic and teach them how to reproduce it for themselves.

![Figure 6. Design Process Schematic](image-url)
DESIGN DEVELOPMENT

After finishing the initial background research and fully defining the problem, we began to generate ideas to solve the problem.

IDEATION

Our goal during the ideation process was to come up with as many ideas as possible. To accomplish this we performed a functional decomposition in which each function of our design was addressed separately. A list of as many methods as possible that could be used to perform the specified function was created. All ideas were recorded without evaluation to avoid hindering creativity. To effectively express our ideas we used sketches to illustrate how each idea would function.

After generating as many ideas as possible we created a morphological matrix. Through this process we were able to create various combinations of methods that would perform the device functions. This created numerous possible solutions to our problem and helped generate more ideas.

We then moved on to a mock up model building stage. In this stage we quickly built small models using inexpensive materials to enable us to express our ideas effectively as well to see how our models will function. This allowed us to see how the user would interact with the devices and identify any potential problems with the designs. Specifically, we better observed how the user would access the device through these models and how the clinicians would interface with the device and user. The models allowed us to identify the three major components of our design: the frame structure, how the user interacts with the device, and how the device articulates with the ground.

The next step in the ideation process was to narrow down our ideas. In order to accomplish this we used a controlled convergence and divergence method. By evaluating our ideas against the customer and engineering specifications we were able to eliminate any ideas that were not feasible or did not address are problem adequately. After comparing our ideas, we also realized that many of them were very similar and could be combined into one which led to a final grouping of ideas.

CONCEPTS

After going through the ideation process, both individually and as a team, the following designs were selected as the top six to consider:
Overhead Support with Triangular Frame

The idea behind the triangular design with overhead support was to take advantage of the ability of a triangle to effectively distribute the forces to which they are exposed. This leads to a higher strength frame and will allow for the total amount of required material to be reduced, reducing the cost and weight of the device. Additionally, by supporting the user from above it will be easy to adjust the amount of support given to the user while they are using the device.

Modified Gait Trainer

Gait trainers are a proven way to provide exercise for people with conditions that limit their strength and mobility. However, these devices are expensive and manufactured with materials and techniques that would not be available to a developing community. Thus, this design sought to mimic the desirable features of a gait trainer in a system that would be less expensive and easier to manufacture and that supports the user from the waist and arms.

Open Concept Frame with Overhead Support

The idea behind this design was to minimize how intrusive the device felt to the user. This device supports the user from above. While it is unlikely that this design would be structurally sound, it helped demonstrate how a device could be made to feel more natural for the user. This design was also unique in that it provided leg support for the user.
Standard Walker with Additional Support

The idea behind this device was to take advantage of the simple design used in a standard walker device. While walkers would not provide enough assistance to our users, the addition of an overhead harness support system would allow a walker to provide adequate support. Another feature of this design was the addition of a chair which would allow the user to take breaks and stay in the device longer.

Stationary Frame with Manually Powered Treadmill

The treadmill design was one of the more unique ideas we discussed. In this design, rather than allowing the user to be able to physically walk around a room or hallway the device would remain stationary and a human-powered treadmill (operated by a worker from the clinic) would be used to provide movement. This design would allow for a simpler frame but would require a more complicated system than desired as a result of the treadmill.

Back Support Device

This design was unique in that it supported the user from behind. Rather than using a harness a waist and chest “belt” would be used with arm supports on the sides. When using this device, the user would be able to walk without anything in front of them, making the device feel more natural for the user. To adjust the amount of support, the back and waist support could be raised or lowered.
DECISION MAKING PROCESS

After using the customer requirements and engineering specifications to narrow down our ideas, we created Pugh matrixes for each category as shown below which highlight the strengths and weaknesses of an idea compared to a standard. By doing this we were able to identify our strongest ideas and determine if any improvements could be made. This technique allowed us to select the best idea for each category and therefore improve our overall final design.

FRAME STRUCTURE

For the frame structure we wanted to select a frame that would be strong enough to support our users but use the least amount of material, reducing cost and weight. Another major feature that determined our decision on the frame structure was adjustability (meaning how easily the device accommodates a wide range of users). Since the patients of the clinic vary in size we wanted to make sure that our device would be able to accommodate them all. After our evaluation we concluded that although the triangle system required more material due to its large size, it best met our engineering and customer requirements as shown in the frame structure Pugh matrix below.

Table 2. Structure Pugh Matrix

<table>
<thead>
<tr>
<th>Concept</th>
<th>Triangle</th>
<th>Chair</th>
<th>Cross</th>
<th>Modified Gait Trainer</th>
<th>Gait Trainer</th>
<th>Modified Walker</th>
<th>Triangle Walker</th>
<th>Back Support</th>
<th>Tripod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amount of Material</td>
<td>S</td>
<td>+</td>
<td>+</td>
<td>S</td>
<td>S</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>S</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>D</td>
<td>-</td>
<td>-</td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td>Weight</td>
<td>+</td>
<td>+</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Bulkiness</td>
<td>-</td>
<td>S</td>
<td>-</td>
<td>S</td>
<td>A</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Adjustability</td>
<td>+</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>S</td>
<td>T</td>
<td>+</td>
<td>S</td>
<td>S</td>
<td>+</td>
</tr>
<tr>
<td>Safety</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>-</td>
<td>S</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LRE</td>
<td>+</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>U</td>
<td>+</td>
<td>S</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Ease of Entry</td>
<td>+</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>+</td>
<td>S</td>
<td>-</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Σ +</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>M</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Σ -</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>ΣS</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
For our user interface we came up with several methods to support our users ranging from back supports to abdominal supports to harnesses. A standard medical harness was a strong option for our purpose but was inadequate due to its high cost. We decided to use it as a datum and compared our ideas to it. Upon evaluation we determined that a harness would best suit our needs but we needed to reduce its cost. For the sake of this project, two harnesses were purchased as gifts for the clinic and a low-cost harness will be designed as a part of another separate project in the future.

### Table 3. User Interface Pugh Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Back Support</th>
<th>Harness 1</th>
<th>Chest Support</th>
<th>Standard Harness</th>
<th>Back and Arm Support</th>
<th>Harness 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Distribution</td>
<td>- S</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>- S</td>
<td>S</td>
</tr>
<tr>
<td>Comfort</td>
<td>- -</td>
<td>- D</td>
<td>-</td>
<td>-</td>
<td>- S</td>
<td>S</td>
</tr>
<tr>
<td>Safety</td>
<td>- S</td>
<td>- A</td>
<td>-</td>
<td>-</td>
<td>- S</td>
<td>S</td>
</tr>
<tr>
<td>Ease of Entry</td>
<td>- -</td>
<td>- A</td>
<td>-</td>
<td>-</td>
<td>- S</td>
<td>S</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>+ +</td>
<td>+ T</td>
<td>+</td>
<td>+</td>
<td>+ +</td>
<td>+</td>
</tr>
<tr>
<td>Expected Cost (Materials)</td>
<td>+ +</td>
<td>+ T</td>
<td>+</td>
<td>+</td>
<td>+ +</td>
<td>+</td>
</tr>
<tr>
<td>Expected Cost (Labor)</td>
<td>+ +</td>
<td>+ T</td>
<td>+</td>
<td>+</td>
<td>+ +</td>
<td>+</td>
</tr>
<tr>
<td>Strength</td>
<td>+ -</td>
<td>+ U</td>
<td>+</td>
<td>+</td>
<td>+ -</td>
<td>+</td>
</tr>
<tr>
<td>Σ+</td>
<td>4 3 3 4</td>
<td>4 3 3 4</td>
<td>4 3 5 4</td>
<td>4 3 4 1</td>
<td>4 3 4 1</td>
<td></td>
</tr>
<tr>
<td>Σ-</td>
<td>4 3 5 M 4</td>
<td>4 3 5 M 4</td>
<td>4 3 5 M 4</td>
<td>4 3 4 1</td>
<td>4 3 4 1</td>
<td></td>
</tr>
<tr>
<td>ΣS</td>
<td>0 2 0 0</td>
<td>0 2 0 0</td>
<td>0 2 0 0</td>
<td>0 2 0 0</td>
<td>0 2 0 0</td>
<td>0 2 0 0</td>
</tr>
</tbody>
</table>
GROUND ARTICULATION

When deciding on how the device will articulate with the ground we had to keep in consideration the limited strength of some of our users. Wheels were perhaps the best suited option for our device but are not the most cost efficient. Another option that we came up with was casters. Casters provided us with a cost efficient option but may be more difficult to maneuver. To further reduce the cost we generated different type of sliders that could be incorporated into our design. Using casters as our datum we compared our ideas and concluded that our ideas scored very similar. In the end the strength of the user would determine the type of ground articulation required. Wheels would be a suitable option for patients with minimal strength whereas a combination of casters and sliders would be more adequate for patients with greater strength.

**Table 4. Articulation with Ground Pugh Matrix**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Casters</th>
<th>Tennis Ball</th>
<th>Slider</th>
<th>Bike Wheel</th>
<th>Home-made</th>
<th>Cup-and-Ball</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Force</td>
<td>D</td>
<td>-</td>
<td>-</td>
<td>S</td>
<td>-</td>
<td>S</td>
</tr>
<tr>
<td>Availability</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Cost</td>
<td>A</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Durability</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lock-ability</td>
<td>T</td>
<td>-</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance</td>
<td>-</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maneuverable</td>
<td>U</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>S</td>
</tr>
<tr>
<td>Σ+</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Σ-</td>
<td>M</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>ΣS</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
WEIGHTED DECISION MATRIX

Once we had selected our top three designs we created a weighted decision matrix to determine which design best met our requirements. To determine this we weighed several categories depending on importance to our customer and evaluated each design accordingly. Cost and local reproduction categories were weighted heavily because they determine if the device will actually be implementable in a developing community. Safety and size were given a low weight factor not because they are unimportant but, because we felt that each design was equally safe and didn’t want safety to cause a large discrepancy among our designs. After scoring our top three options, the Overhead Frame proved to be the best design choice.

Table 5. Weighted Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Standard Gait Trainer</th>
<th>Overhead Frame</th>
<th>Back Support</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ability to accommodate a wide range of patients</strong></td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td><strong>LRE</strong></td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Ease of Entry</strong></td>
<td>4</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Low Cost</strong></td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Locally Manufacturable</strong></td>
<td>5</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td>64</td>
<td>67</td>
<td>31</td>
</tr>
</tbody>
</table>
Frame

The frame was designed to support a maximum user weight of 150 lbs without failure, fit through the doorways in the clinic in Guatemala, be easy to move by the user, and be able to withstand some unintended use by children in the clinic. The triangular structures implemented maximize strength and ability to bear weight while minimizing material required. The choice of bamboo as the primary building material makes the structure both strong and light enough to be moved by children with limited mobility and strength.

Composite Joints

The composite joints use methods used to create bamboo structures such as bicycles and enable bamboo poles to be bound together in a durable and stable manner. This method of connecting the bamboo pieces also ensures that the bamboo poles will not have to be punctured, which could lead to cracks or other damage that would reduce the strength of the bamboo.
User Interface

The harness is designed to be easily assembled, easy to use, and comfortable. The design concentrates most of the weight-bearing portion of the harness on the torso and behind so that the legs are free to move. It also distributes the weight over a large portion of the body so that no pinch points or circulation issues are created. It is easy to put on, employing simple metal adjustors and Velcro to accommodate a large range of user sizes.

Casters

Casters will be placed at the bottom of the front two weight-bearing poles of the structure, and allow the user to easy maneuver the device as they walk. Fixed wheels are attached to the bottom of the back two weight-bearing poles so that the device does not swivel too much, and the back will follow the motion of the front casters.

DESIGN FEATURES

Material selection

The use of bamboo as the main structural material is ideal for our device because it has a high strength to weight ratio. Its density is approximately 37.5 lb/ft$^3$ depending on the species, while its tensile strength is around 2170 lb/in2. This enables our structure to be light enough so that users with limited strength can easily move it as they walk. It is also easily obtained in most developing countries and is very clean and renewable (it requires no factory production and a stalk of bamboo only takes four years of growth to reach ideal structural properties).

Maintenance/Lifetime

One of the most fascinating features of bamboo is the rapid rate at which it can grow. It has been estimated that bamboo can grow up to 24 inches in a single day. The rate at which it grows varies with the species as well as with the environment in which it is grown. Bamboo only grows when sprouting (2-4 month period) and will remain the same size for the rest of the year. This regenerative nature of bamboo makes it a better renewable and sustainable raw material when compared to trees.

Bamboo’s fascinating growth rate and versatile properties have made it one of the most sought out material. Many of bamboo’s characteristics resemble those of wood but its growth characteristics and microstructure distinguish it from it. But just like wood, one of the major problems with bamboo is its vulnerability to degrading organisms. Throughout the past years many studies have been conducted intended to find techniques to help preserve bamboo longer.

To make bamboo less prone to various organism attacks such as fungi and insects it is recommended to harvest it during the dry and cooler seasons. The presence of starch in bamboo makes it a ready source of food to various organisms such as fungi and insects which are less active during these times. Removing this starch or contaminating it will make it less attractive to such organisms. Studies have shown that bamboo poles that have been treated to reduce the starch content within them can last up to 10 years while those that remain non-treated can be expected to last from 2 ½ - 3 years (varying among species).
Heat Treating

A big concern with bamboo is that 30-50% of bamboo is likely to yield cracks. This percentage varies among the different species of bamboos and can be influenced by the different methods used to treat the bamboo. To help preserve bamboo and avoid the accumulation of cracks, it can be treated using several methods which include chemical and heat treatments. The purpose of these treatments is to remove the moisture and sugars within the bamboo and therefore harden the bamboo to increase its strength.

Bamboo has high moisture within its culm. It also contains various sugars within its fibers. When sugar is heated to a specified temperature, it loses its elasticity and becomes brittle just like when maple syrup becomes maple candy when heated. When the sugars harden, they bind the fibers together of the bamboo and increase its strength. It is important to apply even heat distribution along the bamboo pole to avoid uneven shrinkage which could produce additional stress within the pole and promote splitting. To obtain satisfactory results during the heat treatment process See Appendix D for heat treating procedure.

Composite Joints

To avoid drilling holes into the bamboo poles that could promote the generation of cracks, we decided to join our bamboo poles using composite joints. These joints consist of natural hemp fiber along with an epoxy resin and a hardener. The technique of using fibers reinforced with epoxy resins dates back to the 80’s. Bamboo bike builders today have adopted this method which initially consisted of using carbon fiber to produce abnormal geometry bike joints. Throughout the years bike builders have gone from using carbon fiber to using natural fibers. This conversion was produced by the fact that bamboo has a high coefficient of thermal expansion and carbon has a very low coefficient of thermal expansion. This variation in coefficient of thermal expansion would cause the joints to become loose and eventually come apart. Natural fibers have a coefficient of thermal expansion similar to that of bamboo which helped resolved this problem and since then have been adopted. The success of this method is based on the fact that the materials used to produce these joints work together to overcome each other’s deficits. The plastic resins of epoxy are strong in compression but weak in tension whereas the hemp fibers are weak in compression but strong in tension. These composite joints have been tested and verified to withstand stresses produced by a bamboo bike traveling at speeds over 50 mph. To obtain a strong and proper joint see Appendix E for the procedure.
Caster Union

To join our casters to our device we used a combination of a filler material and epoxy. For our filler material we “shredded” the hemp fibers used in the joints to create short strands of material. Using the same material in the mixture as in the joints reduced the variety of materials that needed to be obtained to produce a bamboo strider.

When the hemp fibers are mixed with epoxy it creates a thick paste. Utilizing this thick paste, we were able to fill our hollow bamboo poles and join our casters to the device without having to drill any holes in the bamboo. It is crucial to correctly level the casters when joining them to the bamboo as if the casters have a slight slant to them it will make directing the device difficult. See Appendix F for the joining procedure.

USER INTERFACE

Harness

Overall, a harness is designed to distribute the weight of a user to several different parts of the body, including the torso and both legs. This helps make sure that no one place is bearing too much weight which could potentially injure the user. As stated earlier, a low-cost harness is being designed as part of a separate project. However, the initial design decisions are summarized here. The torso portion will be made of a breathable nylon-polyester blend and it to be worn over clothing to prevent rubbing. The leg straps will be made from neoprene for comfort and durability. They will include Velcro to attach them to the legs and allow them to be adjustable. The torso portion will also be adjustable using a large Velcro panel. Nylon straps will be used to attach the leg straps to the torso portion as well as to attach the torso portion of the harness to the overhead bar. The straps which do this will be attached to the torso in four places to ensure even weight distribution: two in the front and two in the back. The two left straps will attach to each other above the shoulder, as will the two straps on the right. They will then be attached to two long nylon straps overhead, which will have adjustable lengths using cam buckles (see the “nylon straps” section below).

Figure 14 shows the climbing harness that was used for testing and research as the low-cost harness is being developed. See Appendix G for initial harness drawings.
Lift System

This is an optional system that was included in our prototype and helped to fulfill the requirement of only needing one additional person to help the user approach, attach to, and use the device. The winch was attached to the device by a series of straps and a pulley as shown in figure 15. The user can be put in the harness while seated or laying down. The user’s assistant then attaches the winch to the harness – using a loop built into the harness itself – and can then use the winch to easily lift the user into the correct standing position to use the device. This is done slowly with the assistant using one hand to operate the winch and one to stabilize the user and make sure that they do not fall or swing too much. Once the user is suspended at the proper height, the upper nylon loops are run through the over-the-shoulder harness loops and adjusted so that the user will remain at the height. Once this has been done, the winch can be detached from the harness, leaving the user supported by only the device.

In order to exit the device, the user is situated next to the sitting table and the adjustable straps used to control the user’s height in the device can slowly be loosened to allow the user to gently sit onto the table.

If the winch is not purchased, the user requires the help of more assistants to use the device. To approach the device without using the winch system, one assistant supports the user’s weight while the other assistant secures the harness system to the device. This requires that one of the assistants be strong enough to support the user’s potentially full weight, making the winch system the best option for meeting the design requirements. However, it adds to the overall cost of the device and is not necessary to include if cost is a limiting factor for the particular family or clinic the device is being built for.
Adjustable Nylon Straps

Nylon straps were used to connect the harness to the top of the device. Two small nylon loops were attached using epoxy next to the joints on either side of the overhead bamboo bar. Two longer nylon loops were run through these into a loop created by nylon straps attached to the anterior and posterior sides of the harness. This longer loop was connected to itself using a tension lock, which allowed the amount of user weight supported by the device to be adjusted. The loops attached to the harness were attached to either side of the trunk support portion of the harness and were extended over the shoulder of the user. To attach the harness to the device, one must simply run the two upper loops through these harness loops and attach and adjust their length using the tension lock.

Figure 16. Adjustable Nylon Straps
The analysis for our device was performed based on the simplified diagram shown in Figure 17 and 18. All joints were modeled as pin joints to simplify the analysis. Due to the complexities of analyzing a composite joint made of hemp fibers and epoxy, the joint loadings were compared to the loads experienced by a bamboo bike. Horizontal forces were neglected as they are negligible compared to the weight of the user.

Final analysis was performed for bamboo with a 2.2 inch outer diameter and a 1.8 inch inner diameter (0.2 inch wall thickness). This particular size of bamboo was commonly available at the bamboo nursery we visited in Paso Robles (Paso Bamboo) and is large enough to help alleviate any preconceived impressions that the bamboo may not be strong enough. Larger bamboo will make the device even stronger but may become unwieldy and increase the weight of the device.

As bamboo is not an isotropic material it was necessary to consider each type of stress the frame will experience. The analysis calculations can be found in Appendix I and Table 6 summarizes expected bamboo material properties which are based on a compilation of data from a Bamboo wiki page.
Table 6. Summary of Mechanical Properties of Bamboo.

<table>
<thead>
<tr>
<th>Units</th>
<th>N/mm²</th>
<th>PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity</td>
<td>16,170</td>
<td>2.3x10⁶</td>
</tr>
<tr>
<td>Bending Strength</td>
<td>20.27</td>
<td>2940</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>7.86</td>
<td>1140</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>14.96</td>
<td>2170</td>
</tr>
<tr>
<td>Longitudinal Shear Strength</td>
<td>1.41</td>
<td>205</td>
</tr>
</tbody>
</table>

BENDING

Bamboo is strong in bending; however, using the winch system to place a user into the device places a large load in the center of the top pole which leads to a high bending stress. While bending stress analysis was performed on the other frame components we were initially the most concerned with the top beam. After analyzing the beams it was determined that the largest bending stress did occur at the top pole while the user was being placed in the device. Ultimately, the largest expected stress was 1990 psi giving a factor of safety of 1.5. This factor of safety is less than the required 2 by analysis; however, the bamboo will only experience this stress during the short period of time when the user is being placed into the device using the winch. After this time the stress dramatically drops. Additionally, the material properties shown in Table 6 are worst-case conditions and testing indicated that the safety factor is higher than this. See the testing section.

DEFLECTION

As it was determined that none of the beams were expected to fail due to the loadings they would experience deflection was not a large concern except for at the top support bar. This pole was important to analyze as, if the pole experienced a large deflection when loaded, it may cause the device to not be tall enough to support the largest potential users. Under worst-case loading the top beam was predicted to only deflect 0.08 inches. This prediction seems small, but, after performing some initial tests on our treated bamboo, does not seem to be of an unreasonable magnitude.

SHEAR STRESS

Bamboo is weakest in shear loadings as the individual fibers grow axially. The top beam of our frame experiences the greatest shear force and was analyzed to determine if failure was expected. After performing the calculations, a maximum shear stress of 119.4 psi was determined which gave a safety factor of 1.72. While this is a lower factor of safety than we initially desired it is based on the worst case shear strength of bamboo. The information presented in Table 6 was unclear if the strength was truly for a shear load or for torsional loading. As a result, tests were performed on our bamboo poles to verify the analysis. See the testing section.
**TENSILE AND COMPRESSIVE STRESS**

The maximum tensile and compressive stresses that the bamboo poles in our frame are 25.9 psi and 32.6 psi respectively. As the ultimate tensile strength is 2170 psi and the ultimate compressive strength is 1140 psi, there is no concern over the poles failing in tension or compression.

**BUCKLING**

One concern of using hollow bamboo poles is that they would buckle when loaded. The four long bamboo poles that make up the majority of the frame were most likely to buckle due to their length. The poles are constrained by the cross bars that are attached with composite joints which helps to constrain the poles and prevent buckling. However, due to the anisotropic properties of bamboo it is difficult to predict exactly how these supporting poles would behave if buckling was to occur. Thus, a worst-case condition was analyzed to determine what would cause one of the long poles to buckle if it was loaded without any supports other than being fixed to the ground on one end. For these conditions the buckling force was determined to be 445.7 lb. The largest compressive load our frame experiences is less than 45 lb. As a result, the bamboo poles are not expected to buckle when loaded.

**COMPOSITE JOINTS**

Theoretically analyzing the composite joints proved to be beyond the scope of our team’s knowledge, but, in order to prove that the composite joints will be strong enough to support a 150 pound user, the joints were compared to those of a bamboo bike. The composite joints of bamboo bike frames can be expected to experience a static load in their joints of 200 lb and a moment of 800 in-lb. These stresses are amplified by the dynamic loads during breaking or dropping off of a curb, yet bamboo bikes joints are able to handle these large loads. The largest load a joint in our frame is expected to experience is 75 lb and the largest moment during loading is 562.5 in-lb while the majority of the joints experience a moment of around 180 in-lb. Additionally, the 562.5 in-lb load assumes that the joints are perfectly rigid when they are not in reality. Therefore, by comparing our frames composite joints to those of a bamboo bike frame, the joints are expected to be able to handle all loadings they may experience.

One concern was how the composite joints would respond if the device were to be used improperly as a “play structure” or if someone was to jump up and grab the top bar as the dynamic load may cause the top composite joints to fail. To account for this, the top bamboo pole rests on top of the side poles and the composite joints are made larger than the other joints in the device. Please see the testing section for a more thorough justification of the composite joints.
SAFETY CONSIDERATIONS

See Appendix H for the safety checklist used to evaluate the strider.

OVERHEAD WEIGHT

One of the biggest safety concerns in this design was the overhead support due to the dangers associated with the weight-bearing beam failing while a person is using the strider. In order to reduce any risk in this component of the design, we have used a safety factor of 2 as a goal for our design. We made sure to meet this goal in our analyses for any sort of failure in this portion of the design, including failure due to impact in the center of the overhead pole. We also ensured that the “footprint” of the device would be wide enough so that the device is not likely to tip over even if used in an improper manner. While the analysis using the available material properties of bamboo did not lead to a safety factor greater than 2 while using the lift system, testing demonstrated that the device was able to safely handle these loads.

SHARP EDGES

The only sharp edges of the design occur where the casters are connected and in some areas of the composite joints. The casters are near the ground and the sharp bamboo edge is obstructed by the casters. Additionally, the sharp portions of the composite joints were sanded down to minimize the risk of someone cutting themselves on the joints.

EPOXY AND HARDENER

The production of this device required the use of epoxy and hardener. It was important to work in a well-ventilated area to avoid inhaling toxic fumes and to wear gloves while working with the epoxy to avoid irritating one’s skin.
COST ANALYSIS

The low-cost strider for Guatemala project was given a budget of $1500.00 from the Research to Aid Persons with Disabilities Federal Grant – additional funds were given to allow for the donation of two harnesses to the clinic. However, the goal of the project was to create a final strider that could be produced in Guatemala for between $50.00 to $100.00 dollars. Much of the budget was spent on extra bamboo and epoxy so that the heat treatment and composite joint methods could be tested to verify the actual strength and limitations of our design. Additionally, a substantial amount of money was spent on purchasing harnesses to be donated to the clinic for use with our device.

The epoxy and bamboo have the highest cost at $136.70 and $129.60 respectively for the prototype. Extra bamboo and epoxy were purchased to allow for sufficient testing of the device components and to allow for us to practice heat treating bamboo and creating bamboo joints. The overall prototype cost of $377.34 was well within the $1000.00 limit we had set for the prototype cost.

Components of the prototype can be substituted for cheaper alternatives. For example, the casters could be substituted for low-friction sliders (such as tennis balls) which would help to reduce the cost. Additionally, the winch system could be completely eliminated from the system if two or more people were available to help place the user into the device. An alternative method of creating the joints is to drill holes in the bamboo and wrap the poles with rope. While this method is a back-up and does not provide as strong or durable of joints, this would help to further reduce costs. Table 7 summarizes the prototype costs.

By working with Wendy in Guatemala, materials were purchased to be used in the production of the device for the clinic. Table 8 shows the total material costs that went into producing the strider in Guatemala. Bamboo was significantly less expensive in Guatemala than in the United States which greatly helped lower the cost of the device. The cost of epoxy was not significantly different in Guatemala than in the United States though. We believe this is likely due to the fact that epoxy is less readily available in Mexico or Guatemala than in the United States. While we brought casters with our luggage to make the device, based on the hardware stores observed, the cost would be approximately $5.00 per caster. Ultimately, the materials for the strider built in Guatemala totaled to $90.00 which stayed below the goal of $100.00. One thing to note is that this pricing does not include the harness. Designing a low-cost harness proved to be outside the scope of this project so harnesses were donated instead of being produced. As part of an independent study, a low-cost harness will be developed in the fall of 2014. See Appendix K for a complete summary of the project expenditures including both material expenditures and travel expenses.
### Table 7. Prototype Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Vendor</th>
<th>QTY</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated Bamboo</td>
<td>Paso Bamboo</td>
<td>6 poles</td>
<td>$129.60</td>
</tr>
<tr>
<td>Epoxy and Hardener</td>
<td>Entropy Resins</td>
<td>1.5 gal</td>
<td>$136.70</td>
</tr>
<tr>
<td>Casters</td>
<td>McMaster</td>
<td>4</td>
<td>$39.88</td>
</tr>
<tr>
<td>Hemp Bast Fiber</td>
<td>Bamboo Bike Supplies (ebay)</td>
<td>4 lbs</td>
<td>$29.00</td>
</tr>
<tr>
<td>Winch</td>
<td>McMaster</td>
<td>1</td>
<td>$38.09</td>
</tr>
<tr>
<td>Nylon Strap</td>
<td>US Cargo Control</td>
<td>3 feet</td>
<td>$0.69</td>
</tr>
<tr>
<td>Cam Buckle</td>
<td>US Cargo Control</td>
<td>2</td>
<td>$3.38</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>$377.34</strong></td>
</tr>
</tbody>
</table>

### Table 8. Production Costs

<table>
<thead>
<tr>
<th>Part</th>
<th>QTY</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamboo</td>
<td>6 Poles</td>
<td>$10.00</td>
</tr>
<tr>
<td>Epoxy</td>
<td>Approx. 0.5 Gallons</td>
<td>$60.00</td>
</tr>
<tr>
<td>Casters</td>
<td>4</td>
<td>$20.00</td>
</tr>
<tr>
<td>Hemp/Plant Fiber</td>
<td>1.5 lbs</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td><strong>$90.00</strong></td>
</tr>
</tbody>
</table>
MANAGEMENT PLAN

This was a cooperative as well as interdisciplinary project. The three engineering students focused on the design and analysis of the device and the kinesiology member advised the team on the best method of allowing the user to interface with the device. As a cooperative project the work was split among the team members when appropriate to take advantage of the team members’ unique talents and abilities. However, all work was reviewed by the team to insure that the best possible product was delivered to the customer.

PROJECT RESPONSIBILITIES

1. Nicole Cooper
   a. Communications: Responsible for communicating with sponsors and advisors both in SLO and Guatemala.

2. Gonzalo Hernandez
   a. Treasurer: Responsible for keeping track of team expenses for travel and materials.

3. Jared Tower
   a. Secretary: Responsible for tracking project progress and maintaining team binder with relevant work and information.

DESIGN VERIFICATION PLAN

Table 9. Design Verification Plan Summary.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Test Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device Weight</td>
<td>Weigh</td>
<td>26.5 lbs (Pass)</td>
</tr>
<tr>
<td>Support 150 lbs user</td>
<td>Suspend Weight to Verify Strength</td>
<td>Pass</td>
</tr>
<tr>
<td>Safety Factor</td>
<td>Analysis/Qualification by Similarity</td>
<td>1.7 (Testing suggests higher)</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Qualification by Similarity</td>
<td>Pass</td>
</tr>
<tr>
<td>Set-Up Time</td>
<td>User and Clinician Trial</td>
<td>5 min (Pass)</td>
</tr>
<tr>
<td>Height Adjustability</td>
<td>Test Strap/Harness System</td>
<td>Pass</td>
</tr>
<tr>
<td>Braking Force</td>
<td>Pulling Test</td>
<td>0.43 (Pass)</td>
</tr>
<tr>
<td>Device Width</td>
<td>Measure</td>
<td>30” (Pass)</td>
</tr>
<tr>
<td>User Support Percent</td>
<td>Drop Weight to Simulate Fall</td>
<td>Pass</td>
</tr>
<tr>
<td>Distance from User Interface to Sitting Table</td>
<td>Measure</td>
<td>23” (Pass)</td>
</tr>
</tbody>
</table>

The Design Verification Plan (DVP) identifies all design aspects which could fail. Below is a list of specifications and descriptions of how we tested them to make sure that they do not fail. See Appendix I for the official DVP and results.

**Device weight:** to verify that the weight was within our engineering specifications, the device was weighed on the large scale in building 13 of Cal Poly’s campus.
**Fully support a user of 150 lbs:** to verify that the device was able to hold the maximum user weight, we suspended weights from the center of the overhead beam. This device was also moved around once loaded to make sure that the addition of the weight does not cause failure during use.

**Safety Factor:** in order to ensure user safety, we chose to use a goal safety factor of 2 for our design. Our analysis gives a minimum safety factor of 1.7. See the material testing performed on our bamboo.

**Lifetime:** this specification was tested by comparing our design to already existing bamboo structures such as bicycles, as they are the most similar structure to ours which already exists.

**Set-up time:** once our device had been produced at Cal Poly, we practiced going through the device set-up procedure. Additionally, once the device had been built in Guatemala, we tested the device with an actual patient to see how quickly they could be placed into the device.

**Height Adjustability:** to make sure that the harness and frame are able to accommodate multiple sizes of users, we practiced putting on the harness and using the device. We did this ourselves (for group members under the maximum weight limit) and practiced with the user in Guatemala to make sure that the user interface was adjustable and comfortable.

**Braking force:** the braking force was determined by locking the brakes and pulling on the device with a force transducer. This gave the coefficient of friction between the casters and the ground which can be used to determine the force that will cause the device to slip.

**Device width:** to make sure that the device was able to fit through the doors in the clinic, the width was measured using a measuring tape.

**User support percent:** The user support percentage was most concerned with making sure that the device would not fail if a user was to fall. For someone with a large amount of strength the device is more of a safety feature as it is there to catch them in case they fall. To ensure the device met this requirement a 150 pound weight was dropped to simulate a user falling.

**Distance from user interface to sitting table:** this distance was measured using a measuring tape.
MAUFACTURING

The following sections discuss the manufacturing of a bamboo strider, while in Guatemala:

HEAT TREATING THE BAMBOO

The night the team arrived in Guatemala 3 hours were spent treating the bamboo followed by another hour the next morning. The bamboo was heat treated in accordance with the manufacturing procedure as specified in Appendix D; however, due to the limited amount of time in Guatemala, a few procedures were modified to ensure that the device would be completed on time. Instead of performing the 3 passes with a torch that are specified in the procedure, only 2 passes were performed with the torches. Additionally, due to the limited time, the bamboo was not allowed to sit out and dry for a few weeks before being used. To compensate for these modifications the two passes were performed in a way to dry out the bamboo as much as possible without causing damage by overheating it.

CUTTING THE BAMBOO TO SIZE

The bamboo poles were cut to size based on the dimensions specified in Appendix M. The strider made in Guatemala was based on the “3/4 Size” Model due to the small stature of the people in Guatemala. A standard wood hand saw was used to cut the bamboo. During manufacturing we learned that it was easiest to base the size of the front and short side poles off of the actual frame. While the drawings were used as a guideline the irregularities in the bamboo required modifications to be made based off how the device was actually being put together.

Using the handsaw instead of a power saw led to a few irregularities in the device. For example, it was harder to control the length of the poles and if angled cuts were necessary, the saw would often warp leading to an imperfect cut. However, using a hand saw falls more in line with appropriate technology principles. While exploring San Marcos, we did observe shops that either had or sold power tools, so it would be possible to use power tools if one could afford them. Power tools would be most useful while cutting the ends of the bamboo poles at angles as this is where the hand saw led to the most imperfections in cuts.
COMPOSITE JOINTS

The composite joints were created in accordance with Appendix E although, for the sake of time, once again, a few modifications were made. Rather than creating three smaller layers, two thick layers were created for the joints. In addition to manufacturing the strider in Guatemala this way, the strider made at Cal Poly SLO was made and tested this way to verify that the device would still be safe for someone to use. The other change made was that the joints were not sanded down after making intermediate passes or after the last pass except to remove any sharp points on the joint. The main purpose of sanding is to create a joint that is more visually appealing. While this is nice, it is not necessary in making a functional device and by not performing the sanding, much time can be saved. Ultimately, this helped allow us to build the device in Guatemala over the course of three days.

“A” FRAME

The A-Frame revers to the two side supports of the strider. The first step in this process was creating a jig out of plywood and lumber to hold the bamboo poles in place. The cut bamboo poles were then placed into the jig and tied down to ensure that they would not be displaced while the composite joints were created. The tips of the A-Frame were taped together to try to constrain the tips from moving out of place during the process. Once the jig was set-up correctly, the joints to connect the long poles to the short cross bar were created in accordance with Appendix E. Once the joints were finished the A-Frame was removed from the jig and allowed to dry. This process was then repeated for the other side of the device.
FRONT BAR

The first step in joining the front bar to the strider was to join the top bar to the frame by creating joints made from electrical tape. This allowed us to correctly position the strider so that the rest of the pieces would be able to come together correctly. After the top bar was adequately secured, the front bar's length was determined by measuring the distance between the two A-Frames (determined by the length and position of the top bar) and making the necessary cuts using the hand saw. Next, the vertical distance position of the front bar was determined by measuring a length along the side poles and marking the position. One side of the front bar was then taped in place using the electrical tape and a composite joint was created on the other side. After the first joint was completed, the electrical tape was removed and the second composite joint was created. While joining the front bar to the frame we had a difficult time making sure that the front bar was level. In order to fix this problem, hot glue or a similar material could be used to initially secure the front bar in place.

TOP BAR

During the process of joining the front bar to the frame the top bar was taped in place. In order to make the composite joints for the top bar, one side of the tape was removed and the composite joint was created in its place. After the first joint had been completed, the tape on the other side was removed and the second composite joint was created for the top bar.
The first step in joining the casters to the frame was to cut the bottoms of the bamboo side poles at an angle so that the strider would sit flush on the ground. To do this, a piece of wood was used to make a line on the bottoms of the poles that represented where the cuts needed to be made. The strider was then placed on its side and the cuts were made using the hand saw (these cuts were particularly difficult to make using the hand saw). After this, the procedure specified in Appendix F was followed. It was necessary to take special care in ensuring that the casters were properly aligned as if they were slightly tilted it made the device difficult to use as discussed in the mobility section of the testing of the strider.

Figure 26. Caster Integration
TESTING

The following sections describe the testing that was performed on the bamboo and the bamboo strider to verify that the device met the customer’s requirements.

BAMBOO MATERIAL PROPERTIES

At the beginning of the project a significant amount of time was spent trying to find material properties for bamboo. Most of the reports that were found focused only on small sections of the bamboo rather than a piece of bamboo as a whole. Additionally, the properties of bamboo were found to vary from each species of bamboo and even among different pieces of the same type of bamboo. As mentioned in the analysis section, a bamboo wiki page was found where the average material properties of construction type bamboo had been compiled (see Table 6). These properties were used to perform the initial analysis on the bamboo but we wanted to verify the values for the specific type of bamboo we purchased from Paso Bamboo.

To do so, a test system was developed to load bamboo poles in bending. The strong floor in Cal Poly SLO’s composite lab along with two test fixtures, an actuator, a load cell and a digital meter were used in the testing process. The fixtures and actuator were bolted to the strong floor while the load cell was attached to the end of the actuator. A strap was used to connect the load cell to the bamboo poles.

Once the system was correctly set-up the actuator was used to put a force on the center of the bamboo pole which created a bending moment. This was used to simulate the load the strider would experience while supporting a person. The actuator was retracted in small increments and at each stage the load was recorded from the meter and the displacement of the bamboo pole was determined by measuring the length of the actuator arm and subtracting that value from its original length. These measurements, along with the dimensions of the bamboo, allowed us to extract the material properties we needed to verify our design and analysis.
Figure 28 shows the typical results we obtained during the testing. A 2.125” diameter piece of bamboo with a wall thickness of 0.2” was used for this particular test. The test fixture was set up for a 48” spacing. Figure 29 shows the resultant shear and bending diagrams. Ultimately, the pole failed at a stress of 25 ksi (this value was slightly larger than the other tests shown in Appendix N but agrees well). This gives a very large safety factor indicating the material properties discovered in the bamboo wiki were not accurate for the particular bamboo used in this project. Unfortunately, we do not believe that our results are valid for this testing. Throughout the entire process we had issues with the load we were measuring reducing over time from the original load. We believe this can be attributed to a few things. First, we had a difficult time getting the load cell and meter to work properly. The meter constantly needed to be calibrated and would often drift from the calibration even in the middle of a test. Additionally, there were times where the meter would not even recognize the signal from the load cell. At the end of testing, a different meter was used (for the data presented in this section this meter was used) which helped to remove the error from the measuring instruments. Ultimately, even if there is error this extremely large safety factor suggests that the bamboo is more than strong enough for this application.
We believe that the load reduction over time was a result of the visco-elastic properties of bamboo. A visco-elastic material will continue to deform when a constant load is placed on it. However, we determined that part of the load reduction was due to the straps used to attach the load cell to the bamboo. At first we were using a nylon strap with a cam buckle but this led to both stretching of the nylon and slipping at the buckle. To fix this, we tried switching to a braided metal cord with a nylon coating, but this did not solve the problem. The cord continued to stretch and the clamps used to hold the cord in a loop slipped no matter how many were used or how tightly they were clamped down. Next, a seatbelt-like material with a metal carabiner was used but this material stretched as well. As a result, we do not, at this point, have a way of determining how much of the load reduction is due to the bamboo’s behavior and how much is due to our test system’s behavior. We were able to determine the loading that led to failure of the bamboo though as the initial load could be recorded before it began to drop. An important observation from testing was that it was evident when the bamboo was close to failing as it began to audibly crack. Once failure did occur, it did not seem to be catastrophic as the poles would still be attached and able to support a small load.

Even though the data we collected is not entirely valid, we believe it does show that the bamboo is able to meet our design requirements. To be sure, a less complicated test was performed. In the Composites lab, a piece of bamboo was suspended across a 37 inch gap and loaded with 170 lb, giving a moment of 1570 in-lb and a stress of 9.5 ksi. The bamboo was left like this for an hour and a half to determine if the bamboo’s creep would lead to failure and if it would even be able to support this weight without failing. During this time the bamboo did not noticeably permanently deform and once the weights were removed, there was no damage that could be observed. This test proved that the bamboo has the ability to meet our design requirements and that the creep would not lead to failure under any of the operating conditions the bamboo in the strider would experience.

One thing to emphasize is that this testing was for the bamboo we were able to buy in Paso Robles, California. The bamboo used in Guatemala was a different species from what we were able to obtain. However, both types of bamboo can be used for construction. Additionally, based off of our observations and the performance of the strider in Guatemala, it would appear that the bamboo used in Guatemala is stronger than the type tested at Cal Poly.
COMPOSITE JOINTS

The same test fixture used to test the bamboo poles was also used to test the composite joints. However, the test fixtures were bolted in the same slot instead of separated. Test joints were created at 90 degree angles and then loaded by the actuator. The first test joint was constructed using untreated bamboo. When this specimen was tested the bamboo failed before the composite joint did. Even though the joint did not fail, there was a fair amount of deformation but not enough to cause problems while someone would be using the device. The second joint test specimen failed when it experienced a moment of 3000 in-lbf. However, the joint did not catastrophically fail. Instead, the fiber and epoxy began to separate leading to large deformations without being able to support a large load. If the joints were to fail while the strider was being used, one would be able to tell before this would happen and stop using the device. If it did fail, it does not seem that it would fail in a manner that would injure the user. The largest moment a joint is expected to experience during normal operation of the device is 562.5 in-lbf which gives a safety factor of over 5.

During the spring quarter of 2014, two of the project teammates had the opportunity to take the composites class at Cal Poly. As part of one of the lab projects for this course, an attempt was made to determine the mechanical properties of a hemp-epoxy composite. Appendix J contains a summary of the testing and analysis that was performed. While there were some questionable results, the experiment did help to give an idea of the strength of the composite joints. More importantly, it led to a better understanding of how the hemp-epoxy composite joints should be made – specifically, the best ratio of epoxy to hemp fiber.

LOAD CAPACITY AND MOBILITY TESTING

Before traveling to Guatemala, the device created at Cal Poly was tested while supporting the maximum rated user weight. To do this, the lift system was used to suspend 150 lbs of weight. The device was then pushed around to test if the bamboo and joints would be able to handle this load. Additionally, this test helped to determine how easy it would be for a user to maneuver the device. Ultimately, the device handled the loads without showing any signs of failure. However, there were times that it was difficult to maneuver the device. The casters had a difficult time moving over cracks in the concrete that the device was being tested on. Additionally, one of the casters was slightly crooked due to a manufacturing error which led to increased difficulty in moving the device.
TESTING WITH PATIENTS

Once the device was built in Guatemala, it was tested with an eleven-year-old girl who weighed approximately 80 lbs. While this particular girl did not have any disabilities, she was about the height of most of the patients and helped give an understanding of how the device works. She commented that the harness did not cause discomfort and that she felt secure in the device. She was able to suspend all of her weight from it without having any issues. To help simulate an actual patient using the device she hopped around on one foot. The device was still easy for her to move around. One comment she did make was that it required significant effort to get the casters to roll over the cracks in the concrete. This confirmed the observation made during the testing at Cal Poly SLO. It additionally became evident that the current lift system was difficult to use and did not help a clinician while lowering the patient once they are done using the device.

Figure 34. User Testing
RECOMMENDATIONS

After visiting the clinic in San Marcos and re-creating the entire apparatus over the course of three days, the team has several recommendations for this project in the future. These recommendations range from manufacturing capabilities to part or material alternatives and will be followed up on in the fall by Nicole as she completes her degree. Our main recommendations are as follows:

JOINT MANUFACTURING

After analyzing samples of the joint composites, the team recommends that extra care be made in wrapping the fibers around the joints in order to ensure maximum strength. To do this, fibers should be placed at angles of $0^\circ$, $45^\circ$ and $90^\circ$ to the applied load. Therefore when initially adding fibers to the joint (after covering it in a layer of the epoxy mixture), short pieces of the fiber should be laid on the epoxy so that they are at these angles to the load (see Appendix E). The rest of the long joint fibers can then be wrapped as before, ensuring that they completely cover the joint and that they are wrapped in a symmetric pattern.

EPOXY SUBSTITUTE

The epoxy used in creating this device is by far the most expensive material. Though we found that it was available locally, this is definitely an area where there could be significant improvement. Two different possible ways of reducing this cost would be to either use an epoxy substitute already on the market or to research how to make an epoxy substitute from local materials. Most epoxy substitutes on the market are not as strong as the epoxy used. However, because the epoxy joints tested were significantly stronger than actually required by maximum device loading, it would be possible to test joints made with an alternative. Though we do not have the expertise, it would also be possible to work with chemical engineers to determine the materials and processes required in making epoxy to see if it would be viable to re-create the epoxy in developing communities.

JIG DEVELOPMENT

It was very difficult to attach the top and front bars of the device while in Guatemala due to the fact that all outdoor work surfaces were very uneven and we did not want to get epoxy on the smooth indoor floors (we also did not want to inconvenience the women living at the convent too much by working inside). To ensure that clinic employees could easily and accurately attach these pieces and avoid making them crooked, we suggest creating a jig that will support the poles which create these joints and hold them in the correct position while the joint is being made and drying.

WHEEL/CASTER DESIGN

The main comment from testing was that it was somewhat difficult to control the device or move it over cracks in the concrete. Using larger casters in the front and single-axis wheels in the back may help to solve this issue.
LIFT SYSTEM

The lift system was difficult to use even though it did help to place the user into the device. One flaw was that it could not be reversed to help take the user out of the device. A more simple system could be designed that would allow the clinician to both raise and lower the patient into and out of the device.

HEAT TREATING METHOD

The heat treating process was very time consuming and using torches led to uneven heat treatments. Using an oven provided very uniform treating and required little time. However, it was impractical to put 72” long bamboo poles into an oven. Some sort of a cylindrical oven could allow for the quick treatment of bamboo poles and help to create stronger and less time consuming materials for the strider.

HARNESS DEVELOPMENT

The one major part of the design which is significantly too expensive for families or clinics to currently obtain is the harness. The harnesses used in Guatemala were purchased from Kaye Products Inc. and cost about $350 each. In order to avoid this cost, Nicole should work to create a sewing pattern for a comfortable, supportive harness that could be easily made in developing countries.

CONTINUED CONTACT

The team did not have an opportunity to perform testing with patients before leaving Guatemala. As a result, continual contact with the clinic should be maintained to learn how the device is working and if any changes need to be made. Additionally, maintaining contact can help to create future projects to aid this area of Guatemala.
APPENDIX A: INITIAL CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

Customer Requirements:
1. Must be able to be transported to Guatemala (small footprint).
2. Should be able to be reproduced in Guatemala using locally available resources and manufacturing techniques.
3. Allow customer to stand upright and be partially load bearing (user is able to support a variable amount of their own weight with their legs). Adjustable load bearing based on individual needs.
4. Accommodate people with developmental disabilities and amputations as well as those going through physical rehabilitation by allowing them to practice walking with natural walking movements.
5. Prototype should cost less than $500.00.
6. Needs to be as light as possible while still being safe and reliable.
7. Easily set-up.
8. Easy to place customer in standing position using device.
10. Allow for movement but also be able to remain stationary when required.
11. Be accessible from a sitting table

Engineering Specifications:
1. Weigh less than (30) lbs.
2. All parts that must be brought to Guatemala should fit in a (3’x3’x3”) space when unassembled.
3. Be able to suspend up to 150 lbs of weight or provide no support to customer to accommodate various levels of strength.
4. Prototype materials must cost less than $500.00.
5. Designed with safety factor of 3.
6. Still be safe to use after being exposed to environmental conditions for (2) years.
7. Set-up should take less than 5 minutes.
8. Only one assistant needed to place customer in device.
9. Height adjustment to accommodate customers from 3.5 ft tall to 6 ft tall
10. Wheels to allow for movement under (10) lb.
11. Brakes to keep 150 lb stationary on 15 degree incline.
12. Tipping angle at least 10 degrees.
APPENDIX B: QUALITY FUNCTION DEPLOYMENT (QFD)

Below is a Quality Function Deployment Matrix which relates the customer requirements to the relevant engineering specification.

<table>
<thead>
<tr>
<th>Customer Requirements (Step #2)</th>
<th>Engineering Requirements (Hows)</th>
<th>Benchmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be easily transported to Guatemala</td>
<td></td>
<td>5 3 4</td>
</tr>
<tr>
<td>Can be reproduced by other clinics and individuals</td>
<td></td>
<td>5 2 3</td>
</tr>
<tr>
<td>Allows customer to stand and support various amounts of their own weight</td>
<td></td>
<td>1 5 1</td>
</tr>
<tr>
<td>Accommodate developmental disabilities and rehabilitation patients</td>
<td></td>
<td>2 5 1</td>
</tr>
<tr>
<td>Product costs less than $500.00</td>
<td></td>
<td>1 5 1</td>
</tr>
<tr>
<td>Safe and reliable</td>
<td></td>
<td>5 4 3</td>
</tr>
<tr>
<td>Easy to setup</td>
<td></td>
<td>9 6 4</td>
</tr>
<tr>
<td>Easy to use</td>
<td></td>
<td>3 2 5</td>
</tr>
<tr>
<td>Adjustable for children ages 4-15</td>
<td></td>
<td>5 2 2 5</td>
</tr>
<tr>
<td>Able to move under customer’s leg power</td>
<td></td>
<td>5 1 5</td>
</tr>
<tr>
<td>Ability to remain completely stationary without someone holding it</td>
<td></td>
<td>2.5 6 1</td>
</tr>
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<table>
<thead>
<tr>
<th>Units</th>
<th>Ibm</th>
<th>ft²</th>
<th>lb</th>
<th>$/k</th>
<th>weeks</th>
<th>minutes</th>
<th>people</th>
<th>lbf</th>
<th>in</th>
<th>%</th>
<th>ft</th>
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<td>2</td>
<td>5</td>
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<td>3.5</td>
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<td>30</td>
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<td>120</td>
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<td>4</td>
<td>1</td>
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<td>any</td>
<td>8</td>
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<td>Benchmark #2</td>
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<td>100</td>
<td>1250</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>3.4</td>
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<td>40</td>
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<td>5</td>
<td>2</td>
<td>3.4</td>
<td>80</td>
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○ = 9 Strong Correlation
= 3 Medium Correlation
= 1 Small Correlation
Blank = No Correlation
APPENDIX C: GANTT CHART
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<th>Duration</th>
<th>Start</th>
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<th>1st Quarter</th>
<th>2nd Quarter</th>
<th>3rd Quarter</th>
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<td>Pick Project</td>
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<td></td>
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<tr>
<td>2</td>
<td>Watch Presentations</td>
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<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Fill Out Application</td>
<td>1 day</td>
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<td></td>
<td></td>
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<tr>
<td>4</td>
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Project: Gantt Chart
Date: Fri 6/6/14

Tasks:
- Duration-only
- Manual Task
- Manual Summary
- Start-only
- Finish-only
- Deadline
- Progress
- Inactive Task
- Inactive Milestone
- Inactive Summary

External Tasks:
- Manual Summary Rollup

Gantt Chart:
- Project Summary
- External Milestone
- Inactive Task
- Manual Summary
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<tr>
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<th>Duration</th>
<th>Mode</th>
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<td>Wed 10/23/13</td>
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<td>19</td>
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<td>Thu 10/24/13</td>
<td>2 days</td>
<td>20</td>
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<td>21</td>
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<td>Mon 10/28/13</td>
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<td>Thu 10/24/13</td>
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<td>Conceptual Model Presentation</td>
<td>Thu 11/7/13</td>
<td>0 days</td>
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<tr>
<td>29</td>
<td>Conceptual Design</td>
<td>Tue 11/19/13</td>
<td>20 days</td>
<td>29</td>
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<tr>
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<td>Select Best Idea</td>
<td>Tue 11/19/13</td>
<td>0 days</td>
<td>30</td>
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<td>47 days</td>
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<td>0 days</td>
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<td>Wed 4/30/14</td>
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<td>Test Prototype</td>
<td>13 days</td>
<td>Thu 5/1/14</td>
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<td>53</td>
<td>Manual</td>
<td>Field Research in Guatemala</td>
<td>5 days</td>
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<td>54</td>
<td>Manual</td>
<td>Refinement</td>
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<td>Mon 5/26/14</td>
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<td>Final Report Work</td>
<td>10 days</td>
<td>Mon 5/26/14</td>
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<tr>
<td>56</td>
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<td>Design Expo</td>
<td>0 days</td>
<td>Thu 5/29/14</td>
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<td>Final Report Due</td>
<td>0 days</td>
<td>Fri 6/6/14</td>
</tr>
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</table>
APPENDIX D: HEAT TREATMENT PROCESS

Materials:
1. Propane Torch
2. Lighter
3. Cloth
4. Handsaw
5. Safety Glasses

Procedure:
1. Cut the bamboo pole to a length a bit larger than the desired length given that the bamboo can shrink throughout the heat treatment process as it loses its moisture and the sugars inside it harden. Be careful to avoid splitting the bamboo while cutting.
2. Ignite your torch
3. **Initial Pass:** Holding the torch about 5-10 cm away from the bamboo, slowly move back and forth along the direction of growth of the bamboo. During this initial pass, the oils in the bamboo will be removed and the sugars will be hardened. Bubbling should occur and the bamboo should take a yellowish color. Proceed with this procedure one node at a time and wipe off wax as you go to avoid allowing them to be reabsorbed.
4. After the initial pass has been completed throughout the entire pole, allow it to slowly cool in a location away from the sun.
5. **Second Pass:** During the second pass repeat the slow back and forth movement along the direction of the growth of the bamboo until obtaining a light brown color.
7. **Additional Pass:** A subsequent pass is optional to obtain a darker shade finish on the bamboo. You want to avoid overheating your bamboo which can affect the strength of your bamboo.

8. **Sealing the Bamboo:** If desired, apply a coat of a protective sealant to help preserve the bamboo. (recommended)
APPENDIX E: COMPOSITE JOINT PROCESS

Materials:

1. Bamboo
2. Sand paper (40 grit) or electric sander
3. Hemp fiber (2 lbs)
4. Epoxy resin and corresponding hardener
5. Small container
6. Brush
7. Electrical tape
8. Rubber gloves

Procedure: (*Conduct in a well-ventilated area*)

1. Sand down the bamboo area where joint will be located.
2. Place bamboo in desired position.
3. Take some of the hemp fiber and roll it between your hands to create a loose rope approximately 1 inch wide. The loose rope will be able to cover a larger area but also cause the fibers to crisscross as much as possible to produce a strong joint.
4. Mix the epoxy resin and hardener in the container using the proper amount of each ingredient.
5. Apply a coat of epoxy to the area where joint will be located. This is to guarantee that the hemp and epoxy bond properly to the bamboo.
6. Using this loose rope, wrap a layer about ½ inch thick and clamp down the end of the rope. Make sure that the hemp forming the joints extends down the bamboo poles approximately 2 ½ - 3 inches to support the joints.

7. Using the brush, apply the epoxy solution to the wrapped hemp until saturation is achieved. (To get an idea of when this is achieved you can push down on the hemp and notice if any of the mixture flows to the surface).

8. Once saturation is believed to have been achieved, wrap a layer of perforated electrical tape (adhesive side out) to compress the fiber of the joint. Tighten the tape as much as possible avoiding breaking the tape.

9. Massage the joint to drive the mixture further into the hemp and also to remove any excess mixture located on the surface. Wipe off any excess mixture that is removed from the joint during this process.

10. Allow the joint to set until the epoxy is no longer sticky to the touch (setting time varies with epoxy used).

11. Remove the electrical tape

12. Add two more layers repeating steps 5-11. (additional layers could be applied if needed)

13. Once you have applied your final layer you can sand down the joint to enhance its appearance.
APPENDIX F: CASTER BONDING PROCESS

Materials:

1. Hemp Fiber
2. Epoxy resin and corresponding hardener
3. Small container
4. Casters
5. Rubber gloves
6. Tape

Procedure: (*Conduct in a well-ventilated area*)

1. Mix the epoxy and hardener together.

2. Dip the hemp fiber in the solution until saturated.

3. Using the saturated hemp fiber, fill the hollow bamboo about 4-5 inches.

4. Insert the caster stem into the filler material making sure that it is properly leveled.

5. Tape down the caster to make sure that it is properly leveled and allow the filler material to set.
APPENDIX G: INITIAL HARNESS DRAWINGS
LEG STRAP (x 2)
APPENDIX H: SAFETY CHECKLIST

SENIOR PROJECT CONCEPTUAL DESIGN REVIEW HAZARD IDENTIFICATION CHECKLIST

☐ Y ☒ N  Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?

☐ Y ☒ N  Can any part of the design undergo high accelerations/decelerations?

☐ Y ☒ N  Will the system have any large moving masses or large forces?

☐ Y ☒ N  Will the system produce a projectile?

☐ Y ☒ N  Would it be possible for the system to fall under gravity creating injury?

☒ ☐ Y ☒ N  Will a user be exposed to overhanging weights as part of the design?

☒ ☐ Y ☒ N  Will the system have any sharp edges?

☒ ☐ Y ☒ N  Will all the electrical systems properly grounded?

☒ ☐ Y ☒ N  Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?

☒ ☐ Y ☒ N  Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?

☒ ☐ Y ☒ N  Will there be any explosive or flammable liquids, gases, dust fuel part of the system?

☒ ☐ Y ☒ N  Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?

☒ ☐ Y ☒ N  Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?

☒ ☐ Y ☒ N  Can the system generate high levels of noise?

☒ ☐ Y ☒ N  Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc…?

☒ ☐ Y ☒ N  Will the system easier to use safely than unsafely?

☒ ☐ Y ☒ N  Will there be any other potential hazards not listed above? If yes, please explain below?
APPENDIX I: ANALYSIS CALCULATIONS
Top Joint Analysis

\[ \Sigma F_y = 0 \]
\[ -75 + 2A \cos(17°) = 0 \]
\[ A_y = A \cos 17° \]
\[ A_x = A \sin 17° \]

\[ A = B = 39.2 \text{ lb} \]
\[ A_z = B_z = 37.5 \text{ lb} \]
\[ A_x = 11.5 \text{ lb} \]
\[ A_y = -11.5 \text{ lb} \]
\[ \Sigma F_x = 0 \]
\[ C - A_{xz} = 0 \]
\[ \Sigma F_z = 0 \]
\[ D_z - A_z = 0 \]
\[ \Sigma M_D = 0 \]

\[ -z_1 C - x_1 A_z + A_{xz} z_2 = 0 \]
\[ C = A_{xz} \]
\[ A_{xz} (z_2 - z_1) = A_z x_1 \]

\[ A_{xz} = \frac{A_z x_1}{(z_2 - z_1)} \]

\[ D_z = 37.5 \text{ kips} \]

\[ |A_{xz}| = 1 \text{ ft} \]

\[ C = 17.9 \text{ kips} \]
\[ M_a = (15 \text{ in}) \left( \frac{150 \text{ lb}}{2} \right) \rightarrow M_a = 112.5 \text{ in} \cdot \text{lb} \]

\[ zM_{ox} = 0 \]

\[ M_a - E_y z_1 = 0 \]

\[ E_y = \frac{M_a}{z_1} \rightarrow E_y = 32.2 \text{ lb} \cdot \text{in} \]
Fixed-Fixed Joint Top Bar Analysis

\[ M_A = M_B = \frac{F \cdot L}{6} = \frac{150 \text{ lbf} \cdot (30 \text{ in})}{6} \]

\[ M_A = M_B = 562.5 \text{ lbf-in} \]
Bending Stress

\[ I = \frac{\pi}{64} \left( d_o^4 - d_i^4 \right) \rightarrow I = 0.635 \text{ in}^4 \]

\[ \sigma = \frac{Mc}{I} \]

\[ c = \frac{d_o}{2} \]

\[ \sigma_{\text{max}} = \frac{(244 \text{ in-lb}) \left( \frac{2}{3} \right)}{0.635 \text{ in}^4} \rightarrow \sigma_{\text{max}} = 422.7 \text{ psi} \]

\[ \tau_{\text{ut, bending}} = 2940 \text{ psi} \]

\[ \tau_{\text{max}} = \frac{2V}{A} \]

\[ = \frac{2 \left( 751 \text{ lb} \right)}{\frac{\pi}{4} \left( 2.2^2 - 1.8^2 \right)} \rightarrow \tau_{\text{max}} = 119.4 \text{ psi} \]

\[ \tau_{\text{ut}} = 205 \text{ psi} \]
Bending Stress

\[ M_{\text{max}} = \frac{1147.9 \text{ in}-\text{lbf}}{0.635 \text{ in}^4} \Rightarrow \sigma_{\text{max}} = 1992 \text{ psi} \]
Bending Stress

\[ M_{\text{max}} = 1125 \text{ in.} \cdot \text{lbf} \]

\[ V_{\text{max}} = \frac{1125 \text{ in.} \cdot \text{lbf}}{0.635 \text{ in}^4} \left( \frac{2.212}{2} \right) \]

\[ V_{\text{max}} = 1950 \text{ in.} \cdot \text{lbf} \]
$$\frac{F l^3}{48 EI}$$

$$E = 1.6 \times 10^6 \text{ psi}$$
$$l = 30 \text{ inches}$$

$$I = \frac{\pi}{64} (d_0^4 - d_i^4)$$
$$d_0 = 2.2''$$
$$d_i = 1.8''$$

$$\delta_{\text{max}} = 0.08''$$
Tensile & Compressive Stress

\[ \sigma_{\text{compression}} = \frac{P}{A} \]

\[ \sigma_{\text{compression}} = \frac{41 \text{ lb}}{\frac{\pi}{4} (2.2 \text{ in}^2 - 1.8 \text{ in}^2)} = 7 \]

\[ \sigma_{\text{comp}} = 32.6 \text{ psi} \]

\[ \sigma_T = \frac{P}{A} \]

\[ \sigma_{T_2} = 25.9 \text{ psi} \]

\[ \sigma_T = \frac{P}{A} \]

\[ \sigma_{T_{29}} = 13.9 \text{ psi} \]
* Reinforced Joint Analysis *

* Worst-case loading *

\[ W = 150 \text{ lb} \times 2 \times 5 \text{ in} \]

\[ M_2 = \left( \frac{150 \text{ lb} \times 2}{2} \right) \times (5 \text{ in}) \]

\[ M_2 = 375 \text{ lb} \cdot \text{in} \]

\[ \sigma = \frac{M_2}{I} = \frac{(375 \text{ lb} \cdot \text{in}) \times (0.25 \text{ in})}{\frac{\pi}{4} (0.25)^4} \]

\[ \sigma = 30.6 \text{ ksi} \]

\[ \varepsilon = \frac{4v}{3A} = \frac{4 \times 75}{3 \pi (0.25)^2} \]

\[ \varepsilon_{\text{max}} = \sqrt{\left( \frac{\sigma_x - \sigma_y}{2} \right)^2 + \varepsilon_{xy}^2} \]

\[ \varepsilon_{\text{max}} = \sqrt{\left( \frac{30.6 \times 10^3}{2} \right)^2 + (510)^2} \]

\[ \varepsilon_{\text{max}} = 15.3 \text{ ksi} \]
Buckling Analysis

\[ F_B = \frac{\pi^2 EI}{(KL)^2} \]

\[ I = \frac{\pi}{64} \left( d_0^4 - d_i^4 \right) \]

\[ K = 2 \text{ (fixed-free)} \]

\[ L = 75 \text{ inches} \]

\[ E = 1.6 \times 10^6 \text{ psi} \]

\[ F_B = \pi^2 \left( 1.6 \times 10^6 \text{ psi} \right) \left( \frac{\pi}{64} \right) \left( \frac{2.2 \text{ in}^4}{2.75 \text{ in}} \right) \]

\[ (2.75 \text{ in})^2 \]

\[ F_B = 445.7 \text{ lbf} \]
TO: Professor Joe Mello
FROM: Carolina Aranda, David DeHaan, Nikki Larsen, and Jared Tower
SUBJECT: ME 412 Project 3 Memo
DATE: June 5, 2014

The motivation for this study was Jared Tower’s senior project. His group used hemp and epoxy for the project, and he was interested in finding hemp’s composite properties. Composite specimens were made in the unidirectional lay-up (0 and 90 degree one-ply laminates) and in [+45/-45]s and [+45/-45/90]s laminates. Strain gauges were placed on all but the last laminate to determine the properties. The last laminate was subjected to a bending test. The results are shown below, as well as some conclusions about the composite properties of hemp.

**Bending Test Results**

![Bending Test Results](image)

*Figure 1. Flexural stress versus flexural strain curve for joint model specimen.*
Looking at the above data, the specimen failed as a result of delamination. Upon inspection it was observed that layers of tape used in the manufacturing process were included in the test specimen. This was a result of needing a longer piece of the composite to insure that the specimen would be loaded in bending. The original specimen for this test was cut too short and needed to be used for a shear test instead. A scrap piece was repurposed for the bending test; unfortunately, this led to the inclusion of the tape in the specimen and likely
greatly reduced the determined values. This does reveal the importance of removing all tape during the manufacturing of subsequent joint layers for the purpose of the STAND Senior Project.

**Tangent Modulus Slope, m:** 215.54 lbs/in  
**Secant Modulus Position:** -.043 inch  
**Secant Modulus Load:** -15.24 lbs

**Flexural Modulus:** Approximately 220 ksi *(not valid result)*  
**Ultimate Strength:** Approximately 5 ksi *(not valid result)*

**Unidirectional Results**
The below graphs show the stress in the 0 and 90 degree hemp composite compared to the strain in the longitudinal direction and transverse direction, respectively. These values were found by looking at the slope of the data points, which was determined to be 2.2Msi and 0.0365Msi, respectively. This is very low compared to published value of a Young's modulus in the longitudinal direction.

![Graph of Stress versus Longitudinal Strain](image)

*Figure 3. Stress versus longitudinal strain for the 0 degree hemp composite.*
Figure 4. Stress versus transverse strain for the 90 degree hemp composite.

The below graph shows the transverse strain compared to the longitudinal strain. The slope of the line represents Poisson’s ratio for this composite. The definition of Poisson’s ratio is the change in lateral (transverse) strain divided by the change in longitudinal strain. This gives a value of 0.525 for the Poisson’s ratio.

Figure 5. Transverse strain versus longitudinal strain for the 0 degree hemp composite.
The graph shows the data from the tensile test of the 45° fiber orientation hemp composite. The strange data in red was caused by the laminate starting to yield. Therefore the data in red should be ignored for purposes of modulus calculation but the first section of good data (in blue) can be used. This slope of shear stress over strain will be the shear modulus. This means that the Shear Modulus ($G_{12}$) was determined to be 66 Ksi which is very low. From $G_{12}$, $F_1$ can be calculated which is just $1/ G_{12}$. Therefore $F_1$ is $1.513 \times 10^{-5}$. 

**Figure 6. 45° hemp composite tensile test- shear modulus**
The graph above shows longitudinal stress vs strain in the longitudinal direction. From this slope, the modulus in the x or longitudinal direction can be calculated. The data calculates the longitudinal modulus to be .169 Msi.

The graph above shows the longitudinal strain versus the transverse strain. This slope gives the $\nu_{xy}$. It was calculated to be 0.277.
Micromechanics

- Unidirectional [0]

Weights:

\[ W_f = 3g \]
\[ W_m = 9.1g \]
\[ W_c = 12.1g \]

Volume Fractions:

\[ V_f = \frac{W_f}{W_c} = 0.248 \]
\[ V_m = \frac{W_m}{W_c} = 0.752 \]
\[ V_c = V_f + V_m = 1 \]

Modulus of Elasticity

\[ E_f = 200Mpa \]
\[ E_m^T = 5 \times 10^5psi = 3447.4Mpa \]

\[ E_1 = V_f \times E_f + V_m \times E_m = 2642.0Mpa = 0.3832Msi \]
\[ E_2 = E_m \times \left( \frac{1 + \xi \eta V_f}{1 - \eta V_f} \right) \]

\[ \eta = \left( \frac{E_f}{E_m} \right) - 1 \]
\[ \xi = 2 \]
\begin{align*}
E_2 &= 2393.1 \text{MPa} = 0.3471 \text{Msi} \\
\text{- [+] laminate} \\
\text{Weights:} \\
W_f &= 48.8 \text{g} \\
W_m &= 159.7 \text{g} \\
W_c &= 208.5 \text{g} \\
\text{Volume Fractions:} \\
V_f &= \frac{W_f}{W_c} = 0.234 \\
V_m &= \frac{W_m}{W_c} = 0.766 \\
V_c &= V_f + V_m = 1 \\
\text{Modulus of Elasticity} \\
E_f &= 200 \text{MPa} \\
E_m^T &= 5 \times 10^5 \text{psi} = 3447.4 \text{ Mpa} \\
E_1 &= V_f \times E_f + V_m \times E_m = 2687.5 \text{MPa} = 0.3898 \text{Msi} \\
E_2 &= E_m \times \left( \frac{1 + \xi \eta V_f}{1 - \eta V_f} \right) \\
\eta &= \frac{\left( \frac{E_f}{E_m} \right) - 1}{\left( \frac{E_f}{E_m} \right) + \xi}
\end{align*}
\[ \xi = 2 \]

\[ E_2 = 2446.9 \text{ Mpa} = 0.3549 \text{ Msi} \]

**Composite Laminate Theory Calculations**

For the \([\pm 45, 90]_s\) laminate a load in the \(z\) directions at the middle of the laminate was applied. Using the values found from the tensile and shear test, the CLT code was run in order to find the first ply failure. The values used for the hemp epoxy are in the following table.

<table>
<thead>
<tr>
<th>Components Used</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness</td>
<td>0.27 in</td>
</tr>
<tr>
<td>Thickness per ply (6 total plies)</td>
<td>0.045 in</td>
</tr>
<tr>
<td>Width</td>
<td>0.732 in</td>
</tr>
<tr>
<td>Length</td>
<td>4 in</td>
</tr>
<tr>
<td>(E_1)</td>
<td>2.2 Msi</td>
</tr>
<tr>
<td>(E_2)</td>
<td>0.036 Msi</td>
</tr>
<tr>
<td>(G_{12})</td>
<td>66 Ksi</td>
</tr>
<tr>
<td>Poison’s ratio, (v_{12})</td>
<td>0.525</td>
</tr>
<tr>
<td>Flexural Ultimate Strength*</td>
<td>5 ksi</td>
</tr>
<tr>
<td>Longitudinal Ultimate Strength</td>
<td>23.5 ksi</td>
</tr>
<tr>
<td>Transverse Ultimate Strength**</td>
<td>244.4 psi</td>
</tr>
<tr>
<td>Shear Ultimate Strength</td>
<td>875 psi</td>
</tr>
<tr>
<td>(M_x)</td>
<td>106.7 lbs-in/in (failure load from test)</td>
</tr>
</tbody>
</table>

* Tape caused delamination of specimen leading to this low ultimate flexural strength
** This value is extremely low. Based on epoxy datasheet would expect the transverse strength to be 9.4 ksi. The fiber may have affected the epoxy properties or the epoxy may not have cured properly

From the CLT code attached, the following was determined. Shows for a bending load only had curving of the specimen.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\varepsilon_1)</td>
<td>5.1592e-18</td>
</tr>
<tr>
<td>(\varepsilon_2)</td>
<td>-3.0674e-18</td>
</tr>
<tr>
<td>(\varepsilon_{12})</td>
<td>-2.3154e-18</td>
</tr>
<tr>
<td>(K_1)</td>
<td>-2.4835e-01</td>
</tr>
<tr>
<td>(K_2)</td>
<td>1.6010e-01</td>
</tr>
<tr>
<td>(K_{12})</td>
<td>3.9916e-02</td>
</tr>
</tbody>
</table>

Assuming

\(ELU=\text{Longitudinal Ultimate Strength}/E_1\) = Ultimate Longitudinal Strain
\(ETU=\text{Transverse Ultimate Strength}/E_2\) = Ultimate Transverse Strain
\(ELTU=\text{Shear Ultimate Strength}/G_{12}\) = Ultimate Shear Strain

Compression ultimate = tensile ultimate
CLT Results

The CLT analysis indicates that failure does occur at this loading as it did in testing. However, these results do not seem entirely valid due to the very low transverse strength. This indicates something went wrong in the manufacturing process that affected the material properties. It is recommended to re-perform the transverse test with a new 90° laminate. However, the results do indicate that the composite lay-up should be re-evaluated for the STAND Senior Project this experiment was inspired by.

Micromechanics Comparison

Micromechanics did not accurately predict the test specimen mechanical properties. Indicates testing must be done to more accurately predict results. Additionally, more testing is needed on the hemp fiber separate from a composite.
### Results

\[ e = \]

\[
\begin{align*}
5.1592 \times 10^{-18} & \\
-3.0674 \times 10^{-18} & \\
-2.3154 \times 10^{-18} & \\
-2.4835 \times 10^{-01} & \\
1.6010 \times 10^{-01} & \\
3.9916 \times 10^{-02} & \\
\end{align*}
\]

\[ \text{ERES} = \]

\[
\begin{align*}
4.5000 \times 10+01 & 3.2629 \times 10-03 & 8.6515 \times 10-03 & -5.5140 \times 10-02 & 4.1459 \times 10+00 & 3.0494 \times 10-01 & \\
4.5000 \times 10+01 & 2.1753 \times 10-03 & 5.7677 \times 10-03 & -3.6760 \times 10-02 & 2.7639 \times 10+00 & 2.0330 \times 10-01 & \\
-4.5000 \times 10+01 & 5.7677 \times 10-03 & 2.1753 \times 10-03 & 3.6760 \times 10-02 & 2.7639 \times 10+00 & 5.3904 \times 10-01 & \\
-4.5000 \times 10+01 & 2.8838 \times 10-03 & 1.0876 \times 10-03 & 1.8380 \times 10-02 & 1.3820 \times 10+00 & 2.6952 \times 10-01 & \\
9.0000 \times 10+01 & -7.2043 \times 10-03 & 1.1176 \times 10-02 & 1.7962 \times 10-03 & 1.6459 \times 10+00 & 6.7330 \times 10-01 & \\
9.0000 \times 10+01 & -8.4563 \times 10-03 & 1.7127 \times 10-02 & 1.7615 \times 10-03 & 2.5224 \times 10+00 & 7.9031 \times 10-17 & \\
9.0000 \times 10+01 & -8.4563 \times 10-03 & 1.7127 \times 10-02 & 1.7615 \times 10-03 & 2.5224 \times 10+00 & 7.9031 \times 10-17 & \\
9.0000 \times 10+01 & 7.2043 \times 10-03 & -1.1176 \times 10-02 & -1.7962 \times 10-03 & 1.6459 \times 10+00 & 6.7330 \times 10-01 & \\
-4.5000 \times 10+01 & -2.8838 \times 10-03 & -1.0876 \times 10-03 & -1.8380 \times 10-02 & 1.3820 \times 10+00 & 2.6952 \times 10-01 & \\
-4.5000 \times 10+01 & -5.7677 \times 10-03 & -2.1753 \times 10-03 & -3.6760 \times 10-02 & 2.7639 \times 10+00 & 5.3904 \times 10-01 & \\
4.5000 \times 10+01 & -2.1753 \times 10-03 & -5.7677 \times 10-03 & 3.6760 \times 10-02 & 2.7639 \times 10+00 & 2.0330 \times 10-01 & \\
4.5000 \times 10+01 & -3.2629 \times 10-03 & -8.6515 \times 10-03 & 5.5140 \times 10-02 & 4.1459 \times 10+00 & 3.0494 \times 10-01 & \\
\end{align*}
\]

\[ \text{SRES} = \]

\[
\begin{align*}
4.5000 \times 10+01 & 7.3751 \times 10+03 & 3.7481 \times 10+02 & -3.6393 \times 10+02 & 4.1459 \times 10+00 & 3.0494 \times 10-01 & \\
4.5000 \times 10+01 & 4.9168 \times 10+03 & 2.4988 \times 10+02 & -2.4262 \times 10+02 & 2.7639 \times 10+00 & 2.0330 \times 10-01 & \\
-4.5000 \times 10+01 & 1.2788 \times 10+04 & 1.8817 \times 10+03 & 2.4262 \times 10+02 & 2.7639 \times 10+00 & 5.3904 \times 10-01 & \\
-4.5000 \times 10+01 & 6.3938 \times 10+03 & 9.4084 \times 10+02 & 1.2131 \times 10+03 & 1.3820 \times 10+00 & 2.6952 \times 10-01 & \\
9.0000 \times 10+01 & -1.5709 \times 10+04 & 2.6737 \times 10+03 & 1.1855 \times 10+02 & 1.6459 \times 10+00 & 6.7330 \times 10-01 & \\
9.0000 \times 10+01 & -1.8363 \times 10+04 & 4.5881 \times 10+03 & 1.1626 \times 10+03 & 2.5224 \times 10+00 & 7.9031 \times 10-17 & \\
9.0000 \times 10+01 & -1.8363 \times 10+04 & 4.5881 \times 10+03 & 1.1626 \times 10+03 & 2.5224 \times 10+00 & 7.9031 \times 10-17 & \\
9.0000 \times 10+01 & 1.5709 \times 10+04 & -2.6737 \times 10+03 & -1.1855 \times 10+02 & 1.6459 \times 10+00 & 6.7330 \times 10-01 & \\
-4.5000 \times 10+01 & -6.3938 \times 10+03 & -9.4084 \times 10+02 & -1.2131 \times 10+03 & 1.3820 \times 10+00 & 2.6952 \times 10-01 & \\
-4.5000 \times 10+01 & -1.2788 \times 10+04 & -1.8817 \times 10+03 & -2.4262 \times 10+02 & 2.7639 \times 10+00 & 5.3904 \times 10-01 & \\
4.5000 \times 10+01 & -4.9168 \times 10+03 & -2.4988 \times 10+02 & -2.4262 \times 10+02 & 2.7639 \times 10+00 & 2.0330 \times 10-01 & \\
4.5000 \times 10+01 & -7.3751 \times 10+03 & -3.7481 \times 10+02 & 3.6393 \times 10+02 & 4.1459 \times 10+00 & 3.0494 \times 10-01 & \\
\end{align*}
\]
```matlab
CODE

% Simple CLT File
% No Hygrothermal!! thus no distinction
%

clear all
close all

% set up a diary file
diary CLTng.dat

% units are US customary (lb, in, E in psi)
%
% total laminate definition in matrix below  
% [ply angles, thicknesses, matl #]
%
% Set up for two materials
%
% Data in there now is
% 1 - Hemp
% 2 - Epoxy
%
% Laminate is defined in this matrix little "L" or l (sorry it looks like a % one)
% [ angle  thick   matl #]
L=[  45.0   1*.045    1;
    -45.0  1*.045    1;
     90.0   1*.045    1;
    -45.0  1*.045    1;
     45.0   1*.045    1]

% this is the total laminate

% size command to get number of plies
n = size(L,1) ;

% Lamina Properties
% matrix for engineering constants
%E1         E2        v12    G12   all     a11     a22
E = [2.2e6 0.036e6 .525 .066e6 0.0e-6 0.0e-6;  % Hemp/epoxy
     5.84e6 .9e6   .2  .3e6    0.0e-6 0.0e-6];  % E-Glass/Epoxy
% a's are CTE's not used yet!

% intialize the ply distance and ABD matrices

h = zeros(n+1,1);
A = zeros(3);
B = zeros(3);
```
D = zeros(3);
% Form R matrix which relates engineering to tensor strain
R = [1  0  0;
     0  1  0;
     0  0  2];

% find the total thickness
total = sum(l,1)
thick = total(1,2);

% locate the bottom of the first ply
h(1) = -thick/2.;
imax = n + 1;
%loop for rest of the ply distances from midsurf
for i = 2 : imax
    h(i) = h(i-1) + l(i-1,2);
end

%loop over each ply to integrate the ABD matrices
for i = 1:n

    %ply material ID
    mi=l(i,3);
    v21 = E(mi,2)*E(mi,3)/E(mi,1);
d = 1 - E(mi,3)*v21;

    %Q12 matrix
    Q = [E(mi,1)/d v21*E(mi,1)/d 0; E(mi,3)*E(mi,2)/d E(mi,2)/d 0; 0 0 E(mi,4)];

    %ply angle in radians
    al=l(i,1)*pi/180;

    %Form transformation matrices T1 for ply
    T1 = [(cos(al))^2 (sin(al))^2 2*sin(al)*cos(al); (sin(al))^2 (cos(al))^2 -2*sin(al)*cos(al); -sin(al)*cos(al) sin(al)*cos(al) (cos(al))^2-(sin(al))^2 ];

    %Form Qxy
    Qxy = inv(T1)*Q*R*T1*inv(R);

    % build up the laminate stiffness matrices
    A = A + Qxy*(h(i+1)-h(i));
    B = B + Qxy*(h(i+1)^2 - h(i)^2);
    D = D + Qxy*(h(i+1)^3 - h(i)^3);

    %load alphs into and array
a=[E(mi,5); E(mi,6); 0.0];

%end of stiffness loop
end

%change the display format for compliance matrix
format short e

A = 1.0*A;
B = .5*B;
D = (1/3)*D;

K = [A, B;
     B, D];

% put in mechanical loads here
% mech loads
Nx=0.0;
Ny=0.0;
Ns=0.0;  % lbs/in
Mx=(-39.062/0.732)*2;  % lbs-in/in
My=0.0;
Ms=0.0;

% builds array of loads
load = [Nx;
        Ny;
        Ns;
        Mx;
        My;
        Ms];

% Plate compliance
% C = [inv(K)];
% solve for strains and curvatures
e = C*load
%
% reduction factor for ultimate (pseudo A-basis use .80)
RF=1
%
% allowable strains reduced to account for ultimate strength after impact
% row1 is Hemp
% row2 is E-glass
% transverse properties assumed same
% load allowable strains into array
%     ELU      ELUP      ETU      ETUP      ELTU
ea = [RF*.0107  RF*.0107  RF*.00679  RF*.00679  RF*.0133;
      RF*.0    RF*.0    RF*.00   RF*.0    RF*.0];
% zero out results array
ERES = zeros(2*n,6); % strain results
SRES = zeros(2*n,6); % stress results

% loop over each ply and calculate strain
for i=1 : n;
    % loop over top and bottom of each ply
    % starting at the top of ply
    for j=1 : 2;
        %
        ply = i;
        loc = j;

        z = h(i-1+j);

        % need angles and transform back to principal directions
        el = [ e(1)+z*e(4); e(2)+z*e(5); e(3)+z*e(6)];

        % ply material ID
        mi = l(i,3);
        v21 = E(mi,2)*E(mi,3)/E(mi,1);
        d = 1 - E(mi,3)*v21;

        % Q12 matrix
        Q = [ E(mi,1)/d v21*E(mi,1)/d 0; E(mi,3)*E(mi,2)/d E(mi,2)/d 0; 0 0 E(mi,4)];

        % ply angle in radians
        al = l(i,1)*pi/180;

        % Form transformation matrices T1 for ply
        T1 = [ (cos(al))^2 (sin(al))^2 2*sin(al)*cos(al); (sin(al))^2 (cos(al))^2 -2*sin(al)*cos(al); -sin(al)*cos(al) sin(al)*cos(al) (cos(al))^2-(sin(al))^2 ];

        % ply strain in principal coords
        ep = R*T1*inv(R)*el;

        % ply stress in principal material coords
        sp = Q*ep;

        % uses MAX Strain criteria
        % failure index now looks at two different materials

        % check fiber direction
        if ep(1) > 0.0;
            FI = ep(1)/ea(mi,1);
            FIF=FI;
        elseif ep(1) < 0.0;
FI = abs( ep(1) )/ea(mi,2);
FIF=FI;

end
%chk transverse direction
if ep(2) > 0.0;
    F1 = ep(2)/ea(mi,3);
elseif ep(2) < 0.0;
    F1 = abs( ep(2) )/ea(mi,4);
end
% if F1 > FI;
FI = F1;
end
% %
% check shear
F1 = abs( ep(3) )/ea(mi,5);
if F1 > FI;
    F1e = F1;
elseif F1 < FI;
    F1e = FI;
end
% FIF is failure index on fiber failure
% F1e is the highest failure index which could be fiber, transverse or
% shear
%load the results array
% strain
ERES(2*i+j-2,1)=l(i);   %ply angle
ERES(2*i+j-2,2)=ep(1);  % strain in ply 1 direction
ERES(2*i+j-2,3)=ep(2);  % strain in ply 2 direction
ERES(2*i+j-2,4)=ep(3);  % strain in ply 12 or shear strain
ERES(2*i+j-2,5)=F1e;    % highest failure index
ERES(2*i+j-2,6)=FIF;    % failure indice on fiber
%stress now, note failure index is based on max strain and just repeated
%here now with the stresses
SRES(2*i+j-2,1)=l(i);   %ply angle
SRES(2*i+j-2,2)=sp(1);  % stress in 1 direction
SRES(2*i+j-2,3)=sp(2);  % stress in 2 direction
SRES(2*i+j-2,4)=sp(3);  % Shear stress in 12
SRES(2*i+j-2,5)=F1e;    % highest failure index
SRES(2*i+j-2,6)=FIF;    % failure indice for fiber or 1 direction
end
% end
ERES=ERES*1
SRES=SRES*1

diary off
EPOXY DATASHEET (SUPER SAP CLR – CLEAR FAST HARDENER)

### Typical Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance (Visual)</td>
<td>White to light yellow</td>
</tr>
<tr>
<td>Color (Hardener)</td>
<td>1-2</td>
</tr>
<tr>
<td>Viscosity (cPs @ 25°C)</td>
<td>2000-4000</td>
</tr>
<tr>
<td>Density (specific gravity @ 25°C, water = 1)</td>
<td>1.17</td>
</tr>
<tr>
<td>Bio-Carbon Content(^2)</td>
<td>18.2% – 25.4%</td>
</tr>
<tr>
<td>Bio-Content by Mass(^3)</td>
<td>30.8% – 45.2%</td>
</tr>
</tbody>
</table>

### Typical Working Properties using compatible Super Sap® Hardener Systems

<table>
<thead>
<tr>
<th>Property</th>
<th>Clear Fast Hardener</th>
<th>Clear Slow Hardener</th>
<th>Casting Fast Hardener</th>
<th>Casting Slow Hardener</th>
<th>Infusion Fast Hardener</th>
<th>Infusion Slow Hardener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardener Product Rev</td>
<td>CF01</td>
<td>CFS02</td>
<td>CF01</td>
<td>CFS01</td>
<td>INF02</td>
<td>INF01</td>
</tr>
<tr>
<td>Mix Ratio by Weight</td>
<td>100:47</td>
<td>100:48</td>
<td>100:43</td>
<td>100:43</td>
<td>300:13</td>
<td>300:13</td>
</tr>
<tr>
<td>Mix Ratio by Volume</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td>2:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mix Viscosity (cPs @ 77°F)</td>
<td>2000-4000</td>
<td>2000-4000</td>
<td>500-1000</td>
<td>500-750</td>
<td>500-1000</td>
<td>500-1000</td>
</tr>
<tr>
<td>System Bio-Content by Mass(^3)</td>
<td>21% – 30%</td>
<td>21% – 30%</td>
<td>21%–30%</td>
<td>21% – 30%</td>
<td>21% – 30%</td>
<td>21% – 30%</td>
</tr>
<tr>
<td>Gel Time (min, 150g @ 77°F)</td>
<td>25</td>
<td>50</td>
<td>90</td>
<td>360</td>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>Thin Film Set (hrs @ 77°F)</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td></td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Tack Free Time (hrs @ 77°F)</td>
<td>3</td>
<td>8</td>
<td>24</td>
<td></td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Cure Cycle (see notes below)</td>
<td>7 days @ 25°C</td>
<td>7-10 days @ 25°C</td>
<td>7-10 days @ 25°C</td>
<td>3 days @ 25°C Post Cure</td>
<td>7-10 days @ 25°C Post Cure</td>
<td>7-10 days @ 25°C Post Cure</td>
</tr>
</tbody>
</table>

### Typical Performance Properties\(^4\)

<table>
<thead>
<tr>
<th>Property</th>
<th>Clear Fast Hardener</th>
<th>Clear Slow Hardener</th>
<th>Casting Fast Hardener</th>
<th>Casting Slow Hardener</th>
<th>Infusion Fast Hardener</th>
<th>Infusion Slow Hardener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Modulus(^5) (psi)</td>
<td>5.0 x 10^2</td>
<td>5.0 x 10^2</td>
<td>4.0 x 10^2</td>
<td>4.0 x 10^2</td>
<td>6.2 x 10^2</td>
<td>6.2 x 10^2</td>
</tr>
<tr>
<td>Tensile Strength(^6) (psi)</td>
<td>9,410</td>
<td>9,410</td>
<td>8,100</td>
<td>8,100</td>
<td>30,100</td>
<td>10,100</td>
</tr>
<tr>
<td>Flexural Modulus(^5) (psi)</td>
<td>4.4 x 10^2</td>
<td>4.4 x 10^2</td>
<td>–</td>
<td>–</td>
<td>5.5 x 10^2</td>
<td>5.5 x 10^2</td>
</tr>
<tr>
<td>Flexural Strength(^6) (psi)</td>
<td>13,534</td>
<td>13,534</td>
<td>–</td>
<td>–</td>
<td>16,000</td>
<td>16,000</td>
</tr>
<tr>
<td>Elongation at Break(^6) (%)</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ig (°F)</td>
<td>240</td>
<td>240</td>
<td>180</td>
<td>180</td>
<td>240</td>
<td>240</td>
</tr>
</tbody>
</table>

\(^2\) ASTM D6866

\(^3\) Uses bio-carbon content number and molecular structure to calculate total percentage of mass derived from bio-sources

\(^4\) Test specimen of neat resin without reinforcement, cured @ 77°F for 24hrs, then post cured @120°F for 2 hrs

\(^5\) ASTM D638 (ISO 527)

\(^6\) ASTM D990 (ISO 178)
# APPENDIX K: COST ANALYSIS

Table K1: Overall Project Expenditures

<table>
<thead>
<tr>
<th>Item</th>
<th>Vendor</th>
<th>QTY</th>
<th>Total Cost</th>
<th>Purchaser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated MOSO Bamboo</td>
<td>Cali Bamboo</td>
<td>4</td>
<td>$97.15</td>
<td>Jared</td>
</tr>
<tr>
<td>Untreated Bamboo</td>
<td>Paso Bamboo</td>
<td>6</td>
<td>$129.60</td>
<td>Jared</td>
</tr>
<tr>
<td>Epoxy and Hardener</td>
<td>Entropy Resins</td>
<td>1.5</td>
<td>$136.70</td>
<td>Jared</td>
</tr>
<tr>
<td>Casters</td>
<td>McMaster</td>
<td>8</td>
<td>$91.49</td>
<td>Jared</td>
</tr>
<tr>
<td>Hemp Fiber</td>
<td>Bamboo Bike Supplies (ebay)</td>
<td>8</td>
<td>$75.00</td>
<td>Jared</td>
</tr>
<tr>
<td>Winch</td>
<td>McMaster</td>
<td>2</td>
<td>$87.91</td>
<td>Jared</td>
</tr>
<tr>
<td>West Systems Epoxy and Hardener</td>
<td>The Composite Store</td>
<td>1</td>
<td>$67.31</td>
<td>Jared</td>
</tr>
<tr>
<td>Reusable Mixing Sticks</td>
<td>The Composite Store</td>
<td>8/pkq</td>
<td>$3.19</td>
<td>Jared</td>
</tr>
<tr>
<td>Mixing Pot</td>
<td>The Composite Store</td>
<td>1</td>
<td>$0.99</td>
<td>Jared</td>
</tr>
<tr>
<td>Disposable Brushes</td>
<td>The Composite Store</td>
<td>1</td>
<td>$21.45</td>
<td>Jared</td>
</tr>
<tr>
<td>Pulley</td>
<td>Amazon</td>
<td>2</td>
<td>$55.90</td>
<td>Jared</td>
</tr>
<tr>
<td>AM'D Carabiner</td>
<td>Amazon</td>
<td>1</td>
<td>$12.56</td>
<td>Jared</td>
</tr>
<tr>
<td>Black Diamond Carabiner</td>
<td>Amazon</td>
<td>1</td>
<td>$10.95</td>
<td>Jared</td>
</tr>
<tr>
<td>Wide Electric Tape</td>
<td>Amazon</td>
<td>6</td>
<td>$36.30</td>
<td>Jared</td>
</tr>
<tr>
<td>Misc. Manufacturing Supplies - gloves, sand paper, torch hose</td>
<td>Home Depot</td>
<td>-</td>
<td>$55.17</td>
<td>Jared</td>
</tr>
<tr>
<td>Gloves and Electric Tape</td>
<td>Rite Aid</td>
<td>-</td>
<td>$12.48</td>
<td>Jared</td>
</tr>
<tr>
<td>Jig Materials - wood, wood glue, string</td>
<td>Home Depot</td>
<td>-</td>
<td>$31.23</td>
<td>Jared</td>
</tr>
<tr>
<td>1/4&quot; thick, 3&quot; width, 2&quot; length steel</td>
<td>McMaster</td>
<td>1</td>
<td>$23.80</td>
<td>Jared</td>
</tr>
<tr>
<td>3/8&quot; thick, 4&quot; width, 1&quot; length steel</td>
<td>McMaster</td>
<td>1</td>
<td>$24.68</td>
<td>Jared</td>
</tr>
<tr>
<td>Climbing Test Harness</td>
<td>The Gear Co-Op</td>
<td>1</td>
<td>$51.53</td>
<td>Nicole</td>
</tr>
<tr>
<td>Second Bamboo Purchase</td>
<td>Paso Bamboo</td>
<td>6</td>
<td>$108.00</td>
<td>Nicole</td>
</tr>
<tr>
<td>Straps and cams for harness attachment</td>
<td>Strapworks</td>
<td>4</td>
<td>$15.03</td>
<td>Nicole</td>
</tr>
<tr>
<td>Seatbelt strap for testing</td>
<td>Strapworks</td>
<td>1</td>
<td>$3.72</td>
<td>Nicole</td>
</tr>
<tr>
<td>Straps and cams for testing</td>
<td>Strapworks</td>
<td>2</td>
<td>$10.85</td>
<td>Nicole</td>
</tr>
<tr>
<td>Mixing Cups and Electric Tape</td>
<td>Rite Aid</td>
<td>-</td>
<td>$16.96</td>
<td>Nicole</td>
</tr>
<tr>
<td>Bernzomatic Torch kits and Propane</td>
<td>Home Depot</td>
<td>-</td>
<td>$45.10</td>
<td>Gonzalo</td>
</tr>
<tr>
<td>Harnesses</td>
<td>Kaye</td>
<td>2</td>
<td>$808.00</td>
<td>Nicole</td>
</tr>
</tbody>
</table>

**Total:** $2,033.04
Table K2: Travel Expenditures

<table>
<thead>
<tr>
<th>Item</th>
<th>Vendor</th>
<th>QTY</th>
<th>Quetzal</th>
<th>USD Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Incidentals</td>
<td>Multiple</td>
<td>-</td>
<td>-</td>
<td>$340.00</td>
</tr>
<tr>
<td>Plane Tickets</td>
<td>Giselle's Travel</td>
<td>4</td>
<td>-</td>
<td>$2,713.92</td>
</tr>
<tr>
<td>Food from Wendy</td>
<td>Wendy</td>
<td>-</td>
<td>2000</td>
<td>$255.10</td>
</tr>
<tr>
<td>Hotel Rooms</td>
<td>Wendy</td>
<td>4</td>
<td>1280</td>
<td>$163.27</td>
</tr>
<tr>
<td>Materials (bamboo)</td>
<td>Wendy</td>
<td>-</td>
<td>150</td>
<td>$19.13</td>
</tr>
<tr>
<td>Transportation between Tapachula and San Marcos</td>
<td>Wendy</td>
<td>-</td>
<td>1800</td>
<td>$229.59</td>
</tr>
<tr>
<td>Payments for Wendy's time (year long)</td>
<td>Wendy</td>
<td>-</td>
<td>3093</td>
<td>$494.52</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$4,215.53</strong></td>
</tr>
</tbody>
</table>
# APPENDIX L: DVP&R

## STAND DVP&R

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Specification</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
<th>Test Stage</th>
<th>SAMPLES</th>
<th>TIMING</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Device Weight</td>
<td>Weight</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Support 150 lb user</td>
<td>Suspend Weight to Verify Strength</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>3</td>
<td>Safety Factor</td>
<td>Analysis/Qual by Sim</td>
<td>100%</td>
<td>Jared</td>
<td>CV</td>
<td>1</td>
<td>A/S</td>
<td>2/10/2014</td>
</tr>
<tr>
<td>4</td>
<td>Lifetime</td>
<td>Qual by Sim</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Set-Up Time</td>
<td>User and Clinician Test</td>
<td>80%</td>
<td>Group</td>
<td>DV</td>
<td>6</td>
<td>T</td>
<td>4/1/2014</td>
</tr>
<tr>
<td>6</td>
<td>Height Adjustability</td>
<td>Test Strap Filament System</td>
<td>100%</td>
<td>Nicole</td>
<td>DV</td>
<td>1</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>7</td>
<td>Braking Force</td>
<td>Force Transducer</td>
<td>90%</td>
<td>Group</td>
<td>DV</td>
<td>3</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>8</td>
<td>Device Width</td>
<td>Measure</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>User Support Percent</td>
<td>Drop Weight and Suspend full weight</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>4</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>10</td>
<td>Distance from user interface to sitting table</td>
<td>Measure</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>I</td>
<td>3/1/2014</td>
</tr>
</tbody>
</table>

## TEST REPORT

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Specification</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
<th>Test Stage</th>
<th>SAMPLES</th>
<th>TIMING</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Device Weight</td>
<td>Weight</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Support 150 lb user</td>
<td>Suspend Weight to Verify Strength</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>3</td>
<td>Safety Factor</td>
<td>Analysis/Qual by Sim</td>
<td>100%</td>
<td>Jared</td>
<td>CV</td>
<td>1</td>
<td>A/S</td>
<td>2/10/2014</td>
</tr>
<tr>
<td>4</td>
<td>Lifetime</td>
<td>Qual by Sim</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Set-Up Time</td>
<td>User and Clinician Test</td>
<td>80%</td>
<td>Group</td>
<td>DV</td>
<td>6</td>
<td>T</td>
<td>4/1/2014</td>
</tr>
<tr>
<td>6</td>
<td>Height Adjustability</td>
<td>Test Strap Filament System</td>
<td>100%</td>
<td>Nicole</td>
<td>DV</td>
<td>1</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>7</td>
<td>Braking Force</td>
<td>Force Transducer</td>
<td>90%</td>
<td>Group</td>
<td>DV</td>
<td>3</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>8</td>
<td>Device Width</td>
<td>Measure</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>User Support Percent</td>
<td>Drop Weight and Suspend full weight</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>4</td>
<td>T</td>
<td>3/10/2014</td>
</tr>
<tr>
<td>10</td>
<td>Distance from user interface to sitting table</td>
<td>Measure</td>
<td>100%</td>
<td>Group</td>
<td>DV</td>
<td>1</td>
<td>I</td>
<td>3/1/2014</td>
</tr>
</tbody>
</table>
APPENDIX M: STRIDER DRAWINGS
NOTES:

1. ALL DIMENSIONS AND TOLERANCES IAW
2. CREATE COMPOSITE JOINT IAW STAND APPENDIX E
3. BIND WITH BAMBOO IAW STAND APPENDIX F
4. ITEM NO. 8, 9, 10 NOT SHOWN
5. FOR ITEM NO. 5, 6, 9, 10 NO PARTICULAR PART NEEDED

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S101</td>
<td>LONG BAMBOO POLE</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>S102</td>
<td>OVERHEAD BAMBOO POLE</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>S103</td>
<td>BAMBOO FRONT BAR</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>S104</td>
<td>BAMBOO SIDE BAR</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>XXX</td>
<td>CASTER</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>XXX</td>
<td>NYLON STRAP</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>3054163</td>
<td>WINCH SYSTEM</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>S200</td>
<td>HARNESS</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>XXX</td>
<td>PULLEY</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>XXX</td>
<td>CARABINER</td>
<td>1</td>
</tr>
</tbody>
</table>

UNITED STATES SPECIFIED
DIMENSIONS ARE IN INCHES
SOLIDWORKS
SURFACE FINISH: N/A
FINISH: NATURAL
TOLERANCES:

< | 0.50
< < | 0.25
< < < | 0.10
ANGULAR: < | 11

DO NOT SCALE DRAWING

DRAWN: [Signature]
CHECKED: [Signature]
APPROVED: [Signature]
EXPLODED VIEW
SCALE 1:15

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For Academic Use Only.
NOTES:
1. USE BAMBOO THAT BEST MEETS SPECIFICATIONS.
2. HEAT TREAT IAW STAND REPORT APPENDIX D.

DETAIL J
SCALE 1:2

0.00
17°
0.20
0.25

LONG BAMBOO SUPPORT POLE

UNLESS OTHERWISE SPECIFIED:
DIAMETERS ARE IN INCHES
SHEET FINISH: N/A
SURFACE FINISH: N/A
TOLERANCES:
X = 0.50
X.X = 0.25
X.XX = 0.10
ANGULAR:
X = 1°

DEBUR AND BREAK SHARP EDGES
COAT SHARP PORTIONS OF BAMBOO

HEAT TREATMENT FINISH

NAME:  WEIGHT: 2.25 LBS
SIGNATURE:  HEAT ASSEMBLY: S100
DATE:  MATERIAL: MOSO BAMBOO

DRAWN:  CHECKED:  APV'D:
SIGNATURE:  DATE:  MFG:

DIMENSIONS ARE IN INCHES
SURFACE FINISH: N/A
TOLERANCES:
X = 0.50
X.X = 0.25
X.XX = 0.10
ANGULAR:
X = 1°

NEXT ASSEMBLY: S100

WEIGHT: 2.25 LBS

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NOTES:
1. USE BAMBOO BOLES THAT BEST MEET SPECIFICATIONS.
2. HEAT TREAT IAW STAND REPORT APPENDIX D.

DIMENSION TABLE

<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>MODEL: A</th>
</tr>
</thead>
<tbody>
<tr>
<td>FULL SIZE</td>
<td>30</td>
</tr>
<tr>
<td>3/4 SIZE</td>
<td>28</td>
</tr>
</tbody>
</table>

OVERHEAD BAMBOO SUPPORT POLE

DIMENSIONS ARE IN INCHES
SURFACE FINISH: N/A
TOLERANCES:
X = ±0.50
XX = ±0.25
XXX = ±0.10
ANGULAR: ±1°

HEAT TREATMENT FINISH
DEBUR AND BREAK SHARP EDGES
COAT SHARP PORTIONS OF BAMBOO

UNLESS OTHERWISE SPECIFIED:
DIAMETERS ARE IN INCHES
MATERIAL: 2.25 INCH DIAMETER MOSO BAMBOO
WEIGHT: 0.95 LBS

SolidWorks Student Edition.
For Academic Use Only.
NOTES:
1. USE BAMBOO THAT BEST MEETS SPECIFICATIONS.
2. APPROXIMATE CUT FOR MITER JOINT WITH S101.
3. HEAT TREAT IAW WITH STAND REPORT APPENDIX D.

1.80

-0.00

0.20

0.50

+0.25

0.10

1.0

27.75

R1.13

-0.05

0.25

0.05

1.0

1.0

R1.13

ISO VIEW
FOR REFERENCE ONLY

DEBUR AND
BREAK SHARP
EDGES

COAT SHARP PORTIONS OF
BAMBOO

DIMENSION:
MODEL: A
FULL SIZE 27.75
3/4 SIZE 25.75

Q.A
MFG
APPV'D
CHK'D
DRAWN

NEXT ASSEMBLY: S100
WEIGHT: 0.88 LBS

SolidWorks Student Edition.
For Academic Use Only.
NOTES:
1. USE BAMBOO POLES THAT BEST MEET SPECIFICATIONS.
2. APPROXIMATE CUT FOR MITER JOINT WITH S101 AT 73 DEGREE ANGLE FROM POLE AXIS.
3. HEAT TREAT IAW STAND REPORT APPENDIX D.

**DIMENSIONS:**

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**DETAIL N**

**SCALE 1:2**

**NOTES:**

1. USE BAMBOO POLES THAT BEST MEET SPECIFICATIONS.
2. APPROXIMATE CUT FOR MITER JOINT WITH S101 AT 73 DEGREE ANGLE FROM POLE AXIS.
3. HEAT TREAT IAW STAND REPORT APPENDIX D.

**MATERIAL:**

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**NEXT ASSEMBLY:** S100

**WEIGHT:** 1.02 LBS

**SCALE:** 1:10

**DWG NO.:** S104

**SIGNATURE:**

**DATE:**

**REVISION:** A

**TITLE:**

**DRAWN:**

**SIGNATURE:**

**DATE:**

**MFG:**

**APPV'D:**

**CHK'D:**

**DRAWN:**

**DIMENSIONS ARE IN INCHES**

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**COAT SHARP PORTIONS OF BAMBOO**

**DEBUR AND BREAK SHARP EDGES**

**DO NOT SCALE DRAWING**

**UNLESS OTHERWISE SPECIFIED:**

<table>
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<th>Dimension</th>
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<td>2.25 INCH DIAMETER</td>
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**FOR ACADEMIC USE ONLY.**

**SOLIDWORKS STUDENT EDITION.**

**NOTES:**

1. USE BAMBOO POLES THAT BEST MEET SPECIFICATIONS.
2. APPROXIMATE CUT FOR MITER JOINT WITH S101 AT 73 DEGREE ANGLE FROM POLE AXIS.
3. HEAT TREAT IAW STAND REPORT APPENDIX D.
## APPENDIX N: BAMBOO TESTING DATA

### Test 1

<table>
<thead>
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### TEST DATA

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### ANALYSIS

| M (lbs-in) | 1641.96 |
| C (in)    | 0.875   |
| I (in^4) | 0.0623  |
| Sigma (psi) | 23050 |

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### ANALYSIS

| M (lbs-in) | 2880 |
| C (in)     | 1    |
| I (in^4)  | 0.1321 |
| Sigma (psi) | 21800 |

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### ANALYSIS

| M (lbs-in) | 4140 |
| C (in)     | 1.063 |
| I (in^4)  | 0.1755 |
| Sigma (psi) | 25060 |
Manual de Instrucciones:
Proyecto de Equipo S.T.A.N.D de la Universidad de Cal Poly,
San Luis Obispo
Negación de Responsabilidad:
Ni el equipo de estudiantes de ingeniería ni la institución de Cal Poly San Luis Obispo se hace responsable de lesiones causadas por productos defectuosos o productos utilizados de manera inadecuada. Los dispositivos recreados por cualquier persona deben de ser examinados apropiadamente antes de ser utilizados. El peso máximo del usuario no debe de ser más de 150 libras. Es importante seguir todas las instrucciones adecuadamente para asegurar que el bambú y las coyunturas estén bien compuestas con materiales adecuados. Si un dispositivo no es capaz de soportar el peso adecuado o no puede funcionar adecuadamente, no lo utilice para prevenir cualquier tipo de accidente.
El Bambú:
El bambú utilizado para construir este dispositivo debe de estar verde y fresco. El diámetro mínimo requerido del bambú es de 2 pulgadas. Bambú de diámetro menos de 2 pulgadas no es recomendado ya que la fortaleza del bambú disminuye con la reducción de tamaño.

Cortando el Bambú:
El primer paso necesario para construir este dispositivo requiere de cortar los pedazos de bambú a los tamaños adecuados. Para poder construir el dispositivo a las medidas adecuadas, las medidas del usuario deben de ser tomadas. Refiérase a la lista de tamaños localizada al final de este manual. Para cortar el bambú utilice un serrucho de mano para madera. Coloque el bambú en una superficie plana y elevada y asegúrese que el bambú no se vaya a menear al cortarlo. Con mucho cuidado, utilice el serrucho para marcar el lugar en donde el corte será hecho. Despacio transite el serrucho sobre el bambú hasta que logre endentar una cortadura en la superficie del bambú. Esta cortadura ayudara a mantener al serrucho en lugar y prevenir que se deslice. Continúe con el corte con cuidado para prevenir que el bambú se raje. Continúe este método hasta que todos los pedazos de bambú estén a la medida adecuada.

Tratamiento Térmico:
Una de las desventajas del bambú es que al secarse, se puede empezar a rajar y partir. Para ayudar a prevenir que esto suceda, el bambú puede ser expuesto a un tratamiento térmico. Este tratamiento ayudara a seco el bambú y a la vez endurecerá la azúcar que lleva dentro para resistir cualquier partiduras. Para completar este tratamiento refiérase a las instrucciones narradas en el procedimiento titulado “Tratamiento Térmico del Bambú”.

Ensamblaje de Estructuras Laterales:
Las primeras partes que serán ensambladas son las partes laterales. Para simplificar este procedimiento y asegurar que los pedazos de bambú estén colocados acertadamente, el uso de una plantilla es recomendado. Para construir la plantilla es importante que los pedazos de bambú formen un ángulo de 34 grados cuando sean ubicados sobre las unidades de madera. Cuando las unidades de madera estén situadas en sus lugares correspondientes, los dos pedazos más largos pueden ser colocados en la plantilla como está ilustrado en la fotografía. Es importante que las puntas se unan apropriadamente y se mantengan en esta posición durante todo el proceso. Cinta adhesiva puede ser utilizada para asegurar y prevenir que las puntas se separen. El pedazo de bambú que va atravesado y conecta los dos pedazos largos puede ser ubicado a continuación como está ilustrado en la fotografía.
Cuando todos los pedazos de bambú estén colocados como están ilustrados en la fotografía, las instrucciones narradas en el procedimiento titulado “Coyunturas Compuestas de Fibra y Resina Epoxi” pueden ser seguidas para ensamblar el pedazo de bambú horizontal a los dos pedazos verticales.

**Conexión Frontal**

Ya que las dos estructuras laterales estén fabricadas, serán conectadas a través de un pedazo de bambú frontal. Este procedimiento es un poco complejo y requiere de más atención al detalle (la colaboración de dos o tres personas es recomendada). Las dos estructuras laterales deben de ser sostenidas en una posición vertical para que las distancias de enfrente y de atrás puedan ser medidas y ajustadas utilizando un metro. Suficiente espacio debe permanecer entre las estructuras para que el usuario pueda entrar y salir del dispositivo con facilidad. Medidas entre 30 a 35 pulgadas son recomendadas para permitir que el dispositivo pueda atravesar por las puertas de la vivienda. Ya que las medidas de enfrente y atrás han sido ajustadas, el pedazo de bambú frontal debe de ser instalado a una altura adecuada para el usuario. Este pedazo frontal será utilizado por el usuario para empujar el dispositivo al caminar y debe de ser instalado en una posición placentera. Para asegurarse que este pedazo sea instalado apropiadamente, utilice el metro para medir la distancia y marque la posición deseada. Después siga las instrucciones narradas en el procedimiento titulado “Coyunturas Compuestas de Fibra y Resina Epoxi” para ensamblar el pedazo de bambú frontal.

**Conexión de Arriba**

El último pedazo de bambú que debe de ser ensamblado es el pedazo de arriba del dispositivo. Para crear esta conexión, coloque el pedazo de arriba sobre la sima de las estructuras laterales y siga las instrucciones narradas en el procedimiento titulado “Coyunturas Compuestas de Fibra y Resina Epoxi”.

**Acoplamiento de Arnés**

El arnés es la pieza de más alto costo requerido para nuestro dispositivo. Los arnés mostrados en la fotografía son recomendados pero cualquier otro arnés que tenga correas ajustables y le administre soporte al abdomen y piernas del usuario funcionara adecuadamente. Lo más importante del arnés es que sea cómodo para el usuario y no le cause ningún tipo de molestia. Un diseño para fabricar un arnés de bajo costo será creado en el futuro y se añadirá una sección para narrar como producirlo.
Tratamiento Térmico del Bambú:

Materiales:
1. Antorcha de gas propano
2. Un encendedor
3. Un trapo
4. Serrucho de mano
5. Lentes protectivos

Procedimiento:

1. Utilizando un serrucho de mano corte el bambú un pie más largo del tamaño deseado. Esto es importante ya que el bambú se encoge al secarse y la azúcar dentro del bambú se endurece. Tenga cuidado para prevenir que el bambú se parta y divida al cortarlo.

2. Asegúrese que la antorcha esté ensamblada apropiadamente y encienda la antorcha utilizando precaución para no quemarse.

3. Pase inicial: Manteniendo la antorcha aproximadamente 5 a 10 centímetros del bambú, despacio mueva la antorcha sobre el bambú en dirección horizontal. Durante este primer pase, la azúcar será endurecida y los aceites removidos. Los aceites se harán visibles en la superficie del bambú y el bambú tomará un color semi-amarillo. Proceda con este procedimiento un nodo a la vez utilizando el trapo para remover la cera que se vaya acumulando en la superficie.

4. Después de haber completado el primer pase sobre el bambú deje que se enfríe en un lugar seco donde no le pegue el sol.

5. Segundo Pase: El método para completar el segundo pase es igual al método utilizado durante el pase inicial. La única diferencia es que el objetivó del segundo pase es de lograr que el bambú cambie del color semi-amarillo a color café claro.
Coyunturas Compuestas de Fibra y Resina Epoxi:

Materiales:
1. Bambú
2. Papel para lijar
3. Fibra de cáñamo u otra planta seca de hoja larga
4. Resina epoxi con catalizador correspondiente
5. Contenedor pequeño con mesclador
6. Una brocha para pintar
7. Cinta adhesiva eléctrica con agujeros
8. Guantes de plástico desechables

Procedimiento: (*EJECUTA EN UN LUGAR BIEN VENTILADO*)

1. Usando el papel para lijar, lije el área de bambú donde la coyuntura será aplicada.

2. Ubique el bambú en la posición deseada.

3. Tome fibra de cáñamo en las manos y enróllela para crear un lazo flojo de aproximadamente ½-1 pulgada. El lazo flojo permitirá cubrir más área y causará que las fibras se crucen lo más posible para producir una coyuntura fuerte.

4. Mezcle la resina epoxi con su catalizador en las porciones adecuadas dentro del contenedor por aproximadamente 2 minutos para asegurarse que la solución este bien mezclada.
5. Utilizando la brocha, aplique una capa de la solución sobre el área donde la coyuntura será colocada. Esto ayudara asegurar que la fibra de cáñamo se consolide apropiadamente al bambú.

6. Utilizando el lazo flojo, envuelva los pedazos de bambú que serán ensamblados. Aplique fibra hasta que una capa de aproximadamente ½ pulgada este cubriendo el bambú. Asegúrese que la fibra de la coyuntura se extienda aproximadamente 2 a 3 pulgadas del área de la unión para reforzarla.

7. Utilizando la brocha, aplique la solución de resina epoxi sobre la fibra sobre el bambú hasta que este saturada. Para poder determinar cuando este saturada, aplique presión sobre la fibra y observe si la solución fluye a la superficie indicando que ya está saturada.

8. Ya que la fibra este bien saturada, envuelva la fibra con la cinta adhesiva eléctrica asegurándose que la parte adhesiva este boca arriba. Esto ayudara a comprimir la fibra y remover cualquier solución de exceso. Aplique presión al envolver la cinta pero con cuidado para prevenir que la cinta no se vaya a romper.

9. Amásame la coyuntura para provocar que la solución fluya hacia el centro y logre cubrir toda la fibra de la coyuntura. Con un trapo remueva cualquier solución que haya sido removida durante el amasamiento.

10. Permita tiempo para que la solución se seque y la coyuntura se endurezca. (El tiempo necesario para que se seque depende en el tipo de resina y catalizador utilizado).

11. Remueva la cinta adhesiva.

12. Aplique dos más capas de fibra de cáñamo repitiendo los pasos 5-11.

13. Ya que la última capa ha sido aplicada, la coyuntura puede ser lijada para mejorar la apariencia.
**Ensamblaje de Ruedas:**

**Materiales:**
1. Resina epoxi y catalizador correspondiente
2. Un contenedor con mezclador
3. Fibra de cáñamo u otra planta seca de hoja larga
4. Rueda con tallo
5. Guantes de plástico desechables.
6. Cinta adhesiva

**Procedimiento:** (*EJECUTA EN UN LUGAR BIEN VENTILADO*)

1. Mezcle la resina epoxi con su catalizador en las porciones adecuadas dentro del contenedor por aproximadamente 2 minutos para asegurarse que la solución esté bien mezclada.

2. Sumerja la fibra de cáñamo en la solución hasta que esté saturada.

3. Coloque la fibra saturada dentro del bambú hasta que esté casi lleno por completo.

4. Coloque el tallo de la rueda dentro de la fibra asegurándose que esté bien nivelada.

5. Usando la cinta adhesiva, asegure la rueda en lugar para que se mantenga nivelada mientras se consolida.