MECE 4361 – 01 Senior Design I

Mesquite Bean Harvester

Team #3, Team 4-I

Alex Salinas, Victoria Garza, Stephanie Ramos, and Carlos Guzman

Dr. Joanne Rampersad-Ammons, Dr. Arturo Fuentes, Mr. Pemelton.

Dr. Noe Vargas-Hernandez

May 10th, 2020

1 FRONT MATTER

1.1 Executive Summary

The honey mesquite tree is native to South Texas and are commonly seen as a nuisance. However, farmers like The Cappadona Family, have been working hard to reintroduce the use of mesquite beans in everyday products such as jellies, coffee, teas, flour, and even natural sweeteners. In order to help mesquite farmers, such as the Cappadonas, Team 4-I has worked meticulously throughout the 2020 Spring Semester at UTRGV to identify various methods of harvesting mesquite beans. A clear understanding of the biology of the honey mesquite tree and the unique limitations they present to mechanizing the harvesting process was also developed. Team 4-I has designed an alternative harvesting method for honey mesquite beans that includes an excitation system to send vibrations through a tree branch to drop ripened beans into a collection system. This will remove the bottleneck of mesquite bean industry.

The current harvesting method for mesquite beans is isolated to manual labor. Workers are required to hand pick ripened mesquite beans through the hottest times of the year in South Texas, since mesquite beans bloom during a window from June to September. This limits productivity immensely and prevents further growth of this industry.

The proposed harvesting system will be a two-part system, excitation and collection. The excitation system will emit localized bending vibrations to a tree branch ranging from 8 Htz to 24 Htz. This frequency range was developed through a finite element analysis of the natural frequency of a range of mesquite beans. The excitation system will send vibrations to the beans at the end of each branch causing all the ripened beans to fall. The beans will then fall into a collection system that was designed to specifically complement localized excitation. The collection system will be able to store a 30-gallon tub and contain a tarp system shaped like a

half funnel. The tarp will guide falling beans into the tub which could be easily replaced or emptied.

The following paper was written to explain the development of the two-part harvesting system. It contains information varying from problem identification to final design specifications. With the development of this harvesting system the mesquite bean industry in South Texas should be able to increase and quickly become the pride of the Valley. We, as a team, are proud of the work done throughout this semester, despite the hardships that were endured because of the COVID-19 outbreak. Team 4-I persevered and are ready to push forward to create a confident, safe, working product for mesquite bean harvesters.

1.1 Contents

1.2.1 Index

1.2.2 List of Tables

1.2.3 List of Figures

1.2 Introduction

Team 4-I is consisted of four intellectual engineering students, Alex Salinas, Victoria Garza, Stephanie Ramos, and Carlos Guzman. Over the course of our engineering student careers, we met throughout our adventures course by course. Our synergy in our various skills and personalities is what lead to the creation of this team. This paper is a summarization of the Senior Design I course, which consists of important and organized research, development, and creation of a project that students can work on during their final year as an undergraduate engineering student at The University of Texas Rio Grande Valley.

The project was initially presented to us by Dr. Joanne Rampersad-Ammons and our team was incredibly excited to work behind an important project that could influence our community.

In the town of Linn, Texas, there is a ranch named the "Cappadona Ranch," where the family who owns the farm currently have a mesquite bean picking business. The Cappadonas have been successful with the use of mesquite beans to make flour, jams, and other desirable food products; however, they are met with an issue. Currently, the only method that is available is through hand-picking all the beans and collecting them for a hand-milling process. Because of this, there is an issue with bottlenecking. With the inefficiency that comes with hand-picking beans, the demand that HEB is requesting cannot be met unless there are more workers hired for manual labor or another solution is found.

Soon after the project was assigned to the senior design team, Dr. Arturo Fuentes and Mr. John Pemelton joined us to provide additional guidance. Our Senior Design team is tasked with finding an engineering solution to effectively pick and collect honey mesquite bean pods for the Cappadona Ranch. If a solution is found, there is a possibility that mesquite beans can be a more reliable resource of food, and we would effectively be removing the bottleneck and the hazards that manual picking gives.

2 PROBLEM IDENTIFICATION

2.1 Intro

The key subjects to investigate are to identify a method of picking mesquite beans quickly in order to remove the bottleneck that human picking has, understand the biology that comes with mesquite beans, the trees themselves, and understand the caveats that come with bean picking. A fundamental understanding of the problem will lead to the best solution that can be developed. Much of the problem with the current method of harvest is very much a biological one, along with a mechanical problem that we need to identify. As engineers, there is a requirement to be flexible and understand every angle possible in order to find the best solution. The following text is the planning and consideration that goes into the identification of what exactly is our issue that we need to solve.

2.1.1 Brainstorming

A large portion of the first couple of weeks were brainstorming and analyzing what was crucial about our problem. We, as a team, sculpted the fundamental issue first and foremost. We all understood that the growing pains of being a booming business meant that if the supply does not meet the demand due to the quantity of raw material being harvested, the business will not do well due to high prices. It is difficult to manually pick each bean pod to reach the level of quantity needed to meet up with demand. It is time consuming and laborious to be out during the summer months in South Texas, so the first solution to come to mind is that it must be quick and simple to harvest a large amount of beans. Immediately, we looked to solutions that have already been created. There are numerous solutions that are currently being used in mass agriculture such as limb shakers, fruit nets that wrap around a tree, and brushes. We, as a team, decided to investigate methods of excitation and collection to synthesize a solution. Investigation into fruit shakers, tarp systems, and excitation machines are some of the fundamental devices that were used in order to facilitate decision and approach. A large influence in our research is the harvest of the olive tree, where a tarp device is wrapped around a tree, allowing for full, global excitation. Also, the harvest of an almond tree, where almonds are shaken by the main stump of the tree, allowing for vibrations to shake an entire tree down to the last almond. Other information that was collected was with Justin Cappadona, the father and part owner of the ranch. Mr. Cappadona expressed what has worked, his methods of picking, and what had not worked during his time in this business venture.

2.2 4 Key Questions

Due to the growing mesquite industry, the demand for mesquite bean-based products has increased. In order to help mesquite ranchers, reach the demand a harvesting system needs to be implemented that was created specifically to meet the frequency requirements and the biology of mesquite beans. To do this, two solutions must be determined. First a solution needs to be found in order to pick the mesquite bean pods while reducing safety hazards. This product needs to be minimally labor intensive, reach at least 15 ft up the tree, and must contain low safety risks. The second solution is a catching system for the falling beans. This product needs to be easily transportable and have high strength properties to withstand the sharp ends of the bean pods.

These products will increase harvesting time by creating a large enough frequency that will allow for a considerable quantity of beans to fall simultaneously and be caught. Currently the only solutions for harvesting mesquite are manual labor and a select few excitations and catching systems that were developed specifically for other fruits and vegetables such as olives, apples, and citrus trees. However, none have effectively been proven to aid the harvesting of mesquite beans.

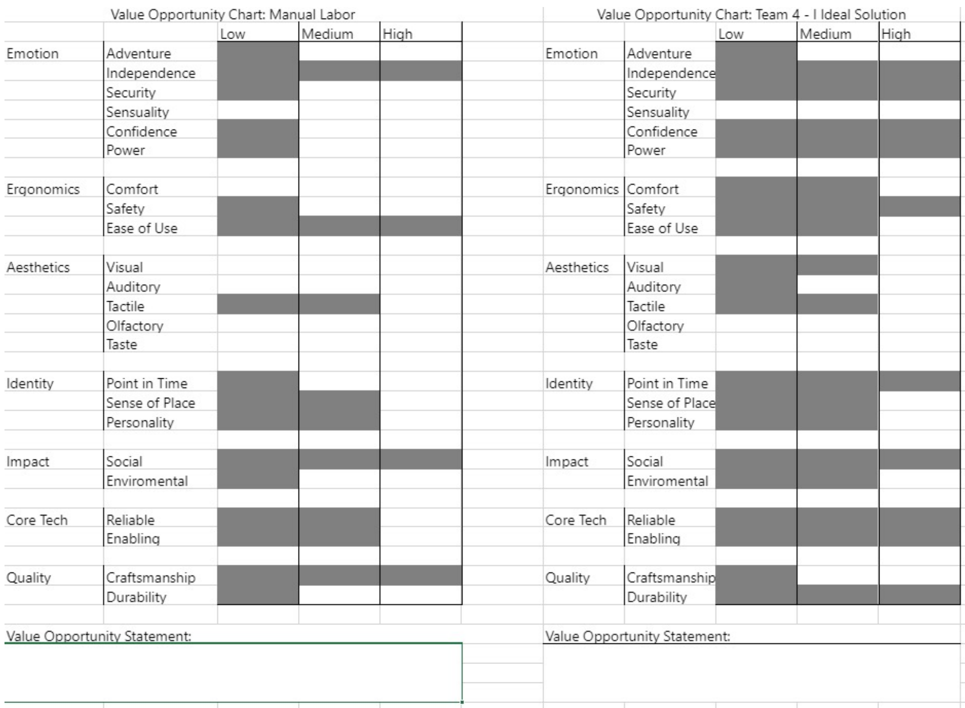


Figure 1: VOA Chart

The Value Opportunity chart or VOA, shown above is a comparison of our main competitive product or resource that is already available. We, as a group, were able to give value to certain qualities that each product could offer compared to the other.

Our product, in theory would be better than the competitive product of manual labor because our product would have a faster picking time which would create large amounts of beans being collected. Our product would also be better to improve the amount of time needed to be at each tree since we would collect the beans much faster than manual labor would. Another large problem that needed to be solved by our product is the safety of the user. Our product would create a much safer work environment since the user would not have to stick their hand into the branches looking for beans and get struck by thorns.

One drawback to our product compared to what is already in place, is that training will have to be done to learn how to use our product correctly and safely. Because the manual labor needs no training, other than learning which bean is ready to be harvested and which is not, it beats our product in that quality. Another thing that our product might be beat out by manual labor is they can get to the nook and crannies of the tree that our product might not be able to reach or excite.

2.3 Proposals

At the beginning of the semester after all projects had been proposed by faculty, the students of Senior Design 1 were tasked to write project proposals to the professors to be chosen for the project. Four project proposals were submitted to be reviewed so that the project that our Senior Design class would revolve around could be chosen.

Two of the proposals were to professors that had already proposed a project. Those projects were this one, that was nicknamed Mesquite, and another nicknamed Heat that was proposed by Mr. Sanchez to fix the long out of commissioned Heat Exchanger that is used in the Heat Transfer Lab.

The other two proposals submitted by our team were two ideas that we came up on our own. The first was one we nicknamed Drinkable that consisted of a water filtration system that could be installed in either underdeveloped communities or in cities hit with disaster that would provide large amounts of clean water. The last idea proposed was a project called Boatside. This project would entail an attachment to the side of the boat that would clean the ocean as the boat went through the water. We proposed that this would be the perfect way to get a large amount of people to clean the ocean water without having to go out of their way to do so. The idea was that a fisherman could easily use our product on the side of his boat while just going about his everyday business.

The following are the proposals submitted for Mesquite and Drinkable. We were asked the 4 Key Questions, what is the problem that is needed to be solved, what is the Product Opportunity GAP, what are current solutions or competitive products already on the market, and what is the Value Proposition.

Mesquite Bean Picker

Code: MESQUITE

- What is the Problem to solve?
  - Mesquite beans, when harvested, are very beneficial in a way that they provide healthier alternatives to gluten products, such as flour, milk, etc.
  - Currently, harvesting mesquite beans is an extremely time-consuming task because they are picked by hand.

- What is the Product Opportunity GAP?
  - Given the growing trend for healthier foods and products, there is a demand for mesquite beans, which calls for a new and more efficient way for harvesting mesquite beans.

- What are the Current Solutions?
  - The current solution literally rests in the hands of mesquite pickers, which is an extremely laborious, time-consuming harvesting method.
  - Our harvester will resemble that of a cherry picker. It will shake the mesquite at a specific frequency that will drop the beans into a tarp-like canopy, which will lead the beans to a container to be collected.

- What is the Value Proposition?

- Given the current harvesting method, which is hand-picking, the machine that will be created will be marketed towards mesquite farms and mesquite farmers.
- Our idea would result in an easier harvesting method that will allow an easier process for the wholesale of mesquite beans.
- The mesquite farmers will be able to produce more product in a much quicker fashion, which will help to encourage the public to use these healthier products.

Filtration and Distillation for Drinkable Water

Code: DRINKABLE

- What is the Problem to solve?
  - Clean, drinkable water is a commodity. For most people, it is easy to obtain, but for some, it is very scarce. Drinkable water is a necessity that should be available to people all over the world, especially in times of crisis.
  - Villages and regions in third world countries are affected by this issue and need an affordable and reliable way to obtain drinking water.
  - Flint, Michigan hits much closer to home, seeing as how they live in the United States and have been with unclean water since 2014.
  - In 2017, Puerto Rico was hit with an awful hurricane and was left in crisis as most of its residents were left without clean water.

- What is the Product Opportunity GAP?
  - We are proposing a multi-filtration system that can be easily assembled. The large amount of contaminated water will undergo filtration phases that will extract large impurities and small contaminants within the water. Then, this water will then be put through a distillation phase that will kill any microorganisms that can cause health issues. After the distillation phase, the filtered water will then exit through a spigot.

- What are the Current Solutions?
  - "Aqua-Marine Water Purifying Straw" is created to filter out toxins on a small scale. (One straw per person)
  - Nanotechnology used to isolate toxins within water and bring them to the surface to clean it out. This is typically not used for drinking water.

- What is the Value Proposition?

- Our affordable product would offer clean water to the masses. The easy assembly would help those in emergency situations, such as those affected by the hurricane in Puerto Rico.
- Our product would be able to turn a large amount of unclean water into filtered, distilled water for those who need it.

2.4 Conclusion

Through this Problem Identification process we have asked the 4 Key questions to reach an understanding of all the projects proposed by professors. This was also a way for our team to reach our own ideas that could be proposed as an idea for a Senior Design project. We showed the comparison of our product and its highest competitor, which in this projects case is manual labor. We proposed projects given to us by professors and came up with a few of our own. This process helped the team become passionate about the project we were choosing to spend the rest of our last year preparing and defending as our last project as undergraduate students.

3 PROBLEM FORMULATION

3.1 Intro

In order to properly and fully formulate our project's problem, one must first identify the logistics of the most important part of the project: The Mesquite Tree and Its Bean Pods. A clear and concise separation between the aspects of this project will allow one to fully comprehend the overall good that this project will consist of and what it could contribute to society. An in-depth look at the background of mesquite and mechanized harvesting, the research pertaining to who the direct and indirect beneficiaries are, the possible competitors that will have to be kept in mind, and design specifications pertaining to the needs and wants of the client right down to the smallest dimension.

3.2 Background Research

3.2.1 History of Mesquite

The mesquite tree (genus *Prosopis*) is a tree/shrub that can grow and thrive in hot, dry climates because of its deep root-growth. Although the mesquite tree grows in many different continents, the honey mesquite tree, known as *P. glandulosa*, is typically found in North America within the southern states of the United States, along with a large variety of other mesquite trees. The honey mesquite tree is known for its bean pods, which have a sweet aroma and flavor. Because of the bean pods' sweetness and nutritional value, they are typically dried and ground into a powder that can be used for a variety of applications.

Back in the indigenous days of the early Americas, Native Americans would pick beans and use them as a food source, source of fuel, dyes, structural material, and even alcohol. Because of mesquite's ability to thrive in arid environments, Native Americans and animals were able to eat the bean pods within the desert. Today, the mesquite tree is seen as an extremely invasive species, and the mesquite tree's versatility and applications are not readily known by much of the public. However, it is a home and attraction to a large amount of wildlife, such as rabbits, coyotes, opossums, birds, butterflies, and many more.

With the Earth's ever-increasing population, alternate methods of food resources are important to investigate in order to discover how one can nutritionally thrive during environmental and social disasters, such as droughts, food shortages, etc. With this concept in mind, using mesquite beans is now more prominent within the American Southwest and is trying to be pushed towards the public.

3.2.2 Miscellaneous

According to many articles, only dry beans are to be collected to be milled. When beans are ripe, they are ready to be picked with almost no effort and could fall off with even the smallest gust of wind. Any beans that are on the trees are to be collected. It is not possible to collect beans from the bare ground due to contaminants from animals, pollutants, and molding from the ground. Containers that the beans are used for collecting must be free from any stones, sticks, branches and other debris. Beans that are soaked, dampened, or damaged by water cannot be milled, and the area must be free of pesticides.

3.3 **Competitive** Analysis

3.3.1 Current Methods of Harvesting Mesquite Beans

Currently, there are very few competitors when it comes to harvesting mesquite beans. The main competitor right now is manual labor. There are no products on the market that are made to harvest mesquite beans, leaving people to harvest them on their own. Through manual labor, arms are scratched up from the thorns of the tree, heat exhaustion is frequent (especially in the summer heat of the Rio Grande Valley), and the safety of the workers is compromised because of the tools that are used to reach the high points of the trees.

Although there are no machines made to cater to mesquite harvesting, there are other harvesters out there that possibly help with harvesting fruits and nuts that could be useful for analysis, such as an olive picker, cherry picker, apple harvester, and nut pickers.

3.3.2 Mechanizing a Harvest

The Alibaba Olive Picker is a machine that can be utilized to pick mesquite beans. The olive picker is powered by gasoline. It contains a throttle operating handle to control the machine, so that a hook-like device hooks onto the branches to vibrate back and forth. This vibration results in the olives falling onto a tarp. This machinery can adjust its length, and it is made from high quality polished steel and aluminum.

Washington State University researchers created a machine in 2012 to pick cherries. Their machine consisted of a metal arm connected to a motor that fastened to the trunk of the cherry tree. When the tree was excited, the cherries would fall into a basin directly underneath. This caused the cherries to become bruised, but it helped with the harvest workload.

The Flex-rake Fruit Picker twists onto a fiberglass pole extension that provides a reach of 20+ feet. It has a basket that is made of a rake, which is the component that takes the fruit off the tree. When the fruit falls in the rake/basket, the foam padding at the base of the basket protects the fruit from bruising.

Due to the mesquite bean's unique geometry, it is very challenging to find a fruit, nut, or vegetable that has a similar shape.

3.3.3 Harvesting Regulations

Because mesquite is a noxious or invasive plant, there are no regulations on harvesting mesquite and the mesquite bean pods.

3.4 Current Patents or Prototypes Under Development

3.4.1 Excitation

Any patents that have been made are only made to cut off branches or to cut mesquite trees down. Additionally, the only patents created for harvesting are for crops that grow close to the ground.

3.4.2 Collection

- US1361029A: FRUIT-COLLECTOR, Druze.
- US2350908A: FRUIT COLLECTOR, Langford.

3.4.3 Competitor Strengths

The strengths of manual labor would be that a worker has a free range of motion and is able to get into the nooks and crannies of mesquite trees. Additionally, a visual quality control is very easy with manual labor.

3.4.4 **Competitor** Weaknesses

The intensive labor is extremely difficult for mesquite harvesters. The thorns from the trees scratch the bodies of the workers. Bees, wasps, and heat exhaustion are aspects that are the weaknesses of manual labor, not to mention body aches and pains.

3.4.5 **Customer** Satisfaction of Competitors

Given that manual labor is not directly connected to the consumer, it is a much slower harvesting method. This results in the supplier not meeting the demands of the stakeholders, which in turn, leads to the consumer being unable to obtain the product that they desire.

3.5 User Research

3.5.1 Who is Our User?

Our products would be able to cater to the needs of mesquite farmers, famers, harvesting companies, landowners, and ranch-hands.

3.5.2 **User** Scenario

Justin and Victoria Cappadona, along with their 3 sons, are the hearts of Cappadona Ranch. In 2016, they transformed the common mesquite bean into delectable delights! However, with their little business booming, they came to realize they needed to harvest a lot more beans to last them the year. The young Cappadonas came to realize there are not any practical methods to harvest mesquite beans due to the tree's unique growing patterns. Each mesquite seems to have a mind of its own. It ranges from a shrub to a tree and has sharp thorns. When picking mesquite, the family uses their tractor to lift their sons high enough to reach the beans growing on the top of the mesquite trees. The family also uses their own arm, eye, and sun protection as they are out during the hottest time of the year. A device is needed to minimize the labor and safety risks and increase harvesting production.

3.5.3 Stakeholders of Our Product and How They Are Affected

A stakeholder is a person or entity that has an interest or concern in a matter, idea, concept, or business that could result in a reputable good for the public.

3.5.4 Stakeholder Map

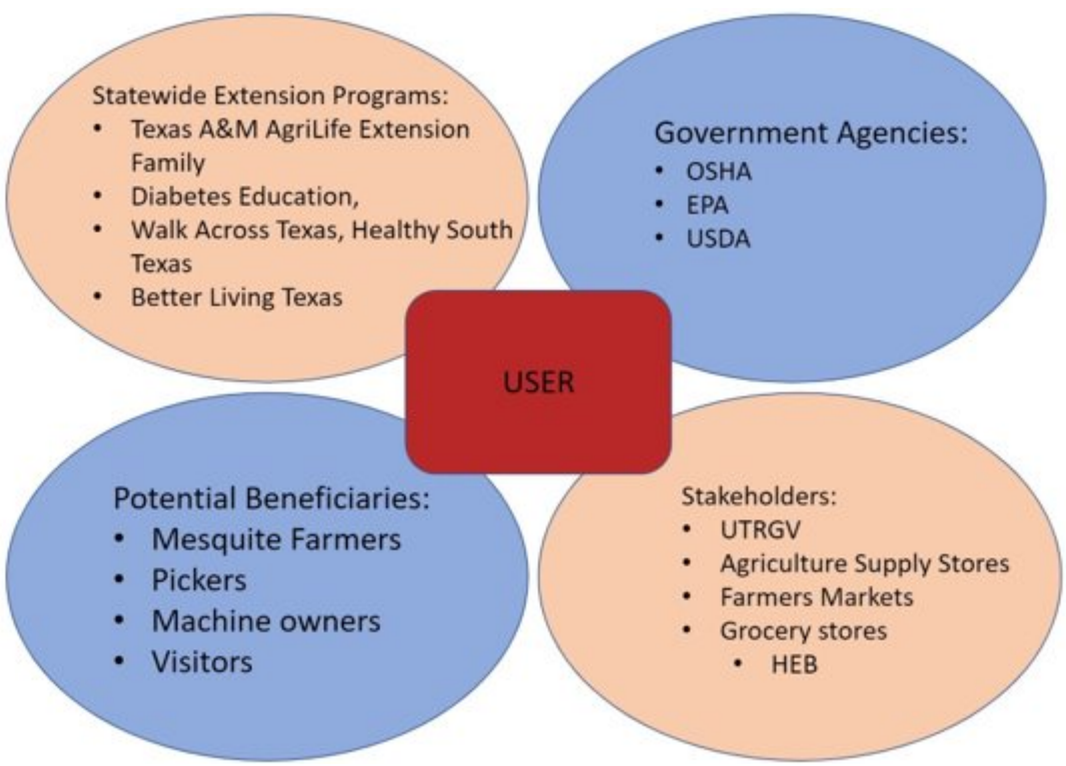


Figure 2: Stakeholder Map for Our Products

3.5.5 Current Stakeholders

These Stakeholders are the stakeholders of the project that will directly benefit from the result of our product.

The University of Texas Rio Grande Valley is the sole owner of this project and will be involved in every patent, copyright, or trademark.

Agricultural Supply Stores and Farmers Markets will benefit from our products because of the increased productivity that our product will create for our users.

Larger chain grocery stores, such as HEB or Whole Foods, will benefit from our product because our user will be able to produce more of their product. For example, the Cappadona's must meet the demand of HEB to continue with the production and selling of their product. With our product, they would save time, money, and energy for more of their product.

3.5.6 Government Agencies Involved

Government agencies such as the Occupational Safety and Health Administration (OSHA), the Environmental Protection Agency (EPA), and the United States Department of Agriculture (USDA).

The OSHA ensures that working conditions for working men and women are safe and healthy by providing trainings, outreaches, education, etc. Their input could possibly be a matter of making sure our products are safe to use with specific trainings.

The EPA ensures the protection of human health and the environment. Their input could possibly be to ensure that our products do not compromise the state of the environment or the health of the workers using our product.

The USDA provides leadership in aspects directly related to food, agriculture, effective management, nutrition, natural resources, and rural development. Their input could possibly help us implement basics in agriculture for the design or application of our product.

3.5.7 Statewide Extension Programs

Statewide extension programs can be public or private special interest groups, organizations, associations, or societies. Some statewide extension programs that are included, but not limited to, are *The Association of Diabetes Care & Education Specialists*, *Better Living for Texans*, *Walk Across Texas*, *Healthy South Texas*, and *Texas A&M AgriLife Extension's Family and Community Health*. Most of these programs are based on human health because our product will enable mesquite farmers to produce more products that are nutritious, gluten-free, and better for one's health. In other words, our product streamlines the process of obtaining mesquite beans, allowing our client to produce their healthy products efficiently and quickly. This allows the consumer to have the healthy products available.

3.5.8 Potential Beneficiaries

The potential beneficiaries of our product could be mesquite farmers, pickers, and machine owners. These beneficiaries will have a way to effectively harvest mesquite beans from mesquite trees.

3.5.9 Pains and Needs of Our User

Given that the current method of harvesting is manual labor and is very labor intensive, there are many health and safety issues that occur. The workers are continuously pricked by thorns, are constantly on dangerous lifts, and are in the sun for very long periods of time. Our user needs to have a safer, mechanized method of harvesting mesquite beans to reduce the loss of their product, increase productivity, and lower the cost of their product.

3.5.10 Boundaries of Our Project

If there are any boundaries to this project, one would be that exciting one side of the mesquite tree could result in the loss of product on the other side of the tree. Another boundary would be that once the bean hits the final point of our collection machine, it is no longer our responsibility.

3.6 Design Specifications

Design specifications are direct guides to the overall design of the product that will be created. Through the information pertaining to design specifications, it can be changed or altered, but in a way that will directly create a better design. Dimensions, aspects of components, and categories of efficiency are not taken lightly, as they are the fundamental aspects for the success of the design of the product. By implementing the requirements of both the customer and engineering principles, a prospective medium can be achieved in the design process.

3.6.1 Customer Requirements

The customers relayed the information that they need a mechanical product to increase productivity. The customers brought up that the design for collection can be reflected to a mesquite tree that is trimmed and groomed. The customers expressed that a tarpaulin system can be used. However, they have expressed concern over the material since the sharp ends of the beans rip the tarp.

3.6.2 Engineering Requirements

The dimensions of the trees should be considered. The maximum diameter of the canopy of the tree is 24 ft, the diameter of the tree trunk is an average of 1-1.25 ft, and the height is at least 20 ft. Vibrations are going to be essential. The vibrations will be localized to the individual branches at the middle of the tree due to the biology of the tree. A low-profile tarpaulin type system will have to be created due to the low canopies of the trees. For the vibrational aspect, the applied excitation frequency will have to be matched with the natural frequency of the mesquite bean to create resonance. Through resonance, the mesquite bean will break off the mesquite tree.

3.6.3 Requirement List

Date Changed	Demand/Want	Requirement List for the Mesquite Bean Picker	Responsibility
  2/18/2020 2/18/2020 3/3/2020 3/3/2020 3/3/2020	 W D D D D	**Geometry** Maximum Radius -- 24 ft. Average Canopy Radius – 15 ft. Arm Extender – 6-12 ft. Localized Collection ($1/2^{th}$ of Canopy Area)	

		Vibration Interface – Meets Branch Perimeter	
3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020	D W W W D W	**Energy** Localized Vibration Battery – 24 Volt Battery -- 12 Volt Gasoline/Motor Rotational Gravitational Freefall Electric (for Vibration)	
4/20/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020	W D W D D W W	**Material** Fiberglass Telescoping Pole Heavy Duty Material for Tarpaulin Aluminum Arm Extender Steel Branch Interface Aluminum Frame (Tarpaulin) Aluminum Hopper	
3/3/2020 3/3/2020 3/3/2020 3/3/2020 4/20/2020	D D W W W	**Signals** Dial for Vibration Control LED Light LED Display Sound for I/O of Vibration Interface Arduino	
3/3/2020 3/3/2020	W D	**Safety** No sharp blades Remove the user from physically	

3/3/2020	D	touching the tree due to thorns Remove the need for standing on elevated height	
  3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020 3/3/2020	 D W W D W W	**Ergonomics** Low profile to account for small canopy height < 50-75 lb. to Maneuver the collection device Can be easily pushed by physical effort < 125 lb. for Easy Movement Ease of Use Handheld Vibration Machine	
	 W	**Costs** < $400 for the whole project	

Table 1: Design Specifications

With this requirement list, the "W" is indicative of a want and the "D" is indicative of a demand.

3.7 Conclusion

To properly and fully formulate our project's problem, we have identified the logistics of the most important part of the project: The Mesquite Tree, Its Bean Pods, and the User. A clear and concise separation between these aspects of this project has allowed the team to fully comprehend the overall good that this project will consist of and what it could contribute to society. An in-depth look at the background of mesquite and mechanized harvesting, the research pertaining to who the direct and indirect beneficiaries are, the possible competitors that will have to be kept in mind, and design specifications pertaining to the needs and wants of the client has allowed us to gain a full knowledge on our project.

3 CONCEPTUAL DESIGN

3.1 Introduction

After all the preliminary information was collected about the biology, the entities to keep in mind, and formulating the end goal in mind, we began to elaborate on the design specifications of our product. With the environment of the outdoors in mind, we communicated and made sure that we keep a couple of essentials in mind. First, we needed to create a device that easy to maneuver and lightweight. With farmers outside a full day, any additional weight or work can be dangerous and incredibly laborious for anyone. Second, our design needed to be adaptive to the random changes in thickness of the branches, canopy diameters, and growth. Third, it must improve safety conditions of the user, where the user does not have to physically pick a tree with thorns.

3.2 Functional Definition

Our product must be separated into different categories in order to fulfill the need of the typical mesquite farmer. Our function of the device has several variables that must be considered, but the main function that must be considered above all else is to pick the honey mesquite bean pods off the tree. Fundamentally, without the function of picking the beans off the tree, everything else in our project would not work since everything is dependent on the bean pods. As a team, we created a functional diagram to visually indicate the different variables that are introduced into our system and how everything is intended to work and synergize together.

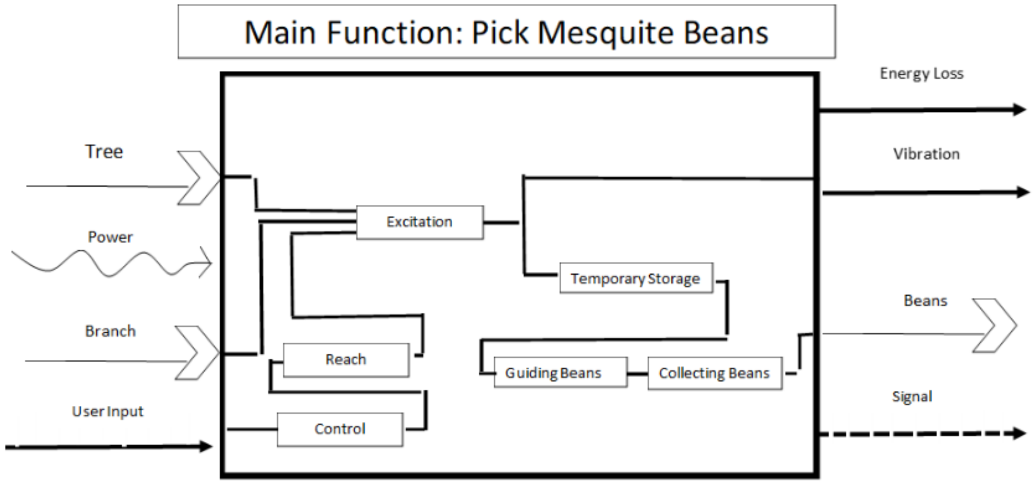


Figure 3: Functional Diagram

Our system must take several inputs into consideration. First, we have the tree and the branch. These two inputs are essential as these carry the bean pods that we are looking for but are also our main subjects where they will be receiving vibrational energy to release these beans. The tree and the branch must go through excitation in order to drop the bean pods, and the only method to do so is through a user input such as a farmer using our excitation machine to shake the tree and the branch. The user must have access to the control of the frequency of the shaker and have the physical reach of going into the branch or trunk of the tree. Once these are considered, and the user input connects with the branch and shakes, the beans are expected to fall. However, the caveat of the project is that the bean pods cannot touch the ground. If they were to touch the ground, then the bean pods could be exposed to the moisture and contamination of the ground and start the buildup of mold, rendering the bean unsafe for consumption. Therefore, the use of temporary storage such as a tarp, hopper or similar uses will have to be used to temporarily store the beans, allow themselves to be guided, and then collected in a universal storage such as a bin or a bucket. Once the beans are collected, users have the option to do with the beans as they please, whether its transport it to a sifting process or take them immediately to storage. There will be several outputs that have to be considered in our system such as, energy loss from the machines that will be using power that is an input to the system, vibrational energy will also be an output and will need to take into consideration to not break or damage the tree branches, a possible signal to the user to show that the harvest is complete, and the final product itself, the honey mesquite bean pods.

This functional diagram that is presented is a general blueprint that we followed in order to understand and fully convey to ourselves the complexity of the system and how we must approach this problem. There may be some revisions that will come to strengthen our design, but for the moment, this is what we, as a team, decided on how the system should work. With all these variables considered, it will heavily influence our design choices and direct the senior design team to the right direction.

3.3 Functional Resolution

3.3.1 Morphological Charts

3.3.1.1 Excitation

During the design process it was evident to the team a key aspect would be distinguishing sub-functions for each system. Through group discussion it was decided excitation would have 5 key subfunctions: branch interface, power, control, method of vibration, and arm extension. This would allow for future design concept variants to be mad with ease. The figure below is a morphological chart that will be used to list all concept ideas for the excitation system. However, this is a tentative chart that is subject to change based on further vibrational analysis. It was brought to our team's attention that a mechanical vibration system may not be the best solution for mesquite trees. Other modes of vibration may be better alternatives to reach the natural frequency of the bean pods such as sound.

The morphological chart below shows the current progress for design concepts of the excitation system. The first subfunction is branch interface. This was decided to be an important subfunction because it dictates how the system will contact the mesquite tree. All the ideas for this subfunction would not only stimulate the branches and beans but would also prevent any damage to the tree. The second subfunction is power sources. The biggest question when thinking of these concepts was, "Which energy source has a large enough power supply to engage our system?" Our next subfunction is control. How will the excitation system be powered on? Will this control system be able to switch through various vibrational frequencies or will it only be set to one specific setting? These are a few questions that were taken into consideration when brainstorming control systems. Next, the vibrational motor was brainstormed. A lot of research was done to find which motor system will provide a large enough frequency to meet the natural frequency of the bean pods. Lastly the arm extension was researched. It is important to know how far it can reach so that the beans at the top of the tree can be reached. We also want to be able to protect any wires that would have to run the length of the machine.

Sub-Functions	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Branch Interface	Adjustable Clamp	Immovable Fork	90° Vibrating Brush	Cupping Brush	Vertical Rotating Brush	Hook
Power	Battery	Electrical Input	Gas/Fuel			
Control	Adjustable Knob	Coded Using Arduino	Trigger	Power Switch	User Control Interface	
Motor	Electric Motor	Servo Motor	Offset Mass Motor	Reciprocating Motor	Cylinder Coreless	
Method of Vibration	Slider Crank	Adjustable Slider Crank	Unbalance Mass			
Arm Extension	Hollow Piping	Adjustable Buttons	Adjustable Arm Length	Telescoping Pole	Solid Piping	

Table 2: Morphological Chart -Excitation

3.3.1.2 Collection

Important subfunctions that must be taken into consideration after the excitation of the mesquite tree are as follows. Collection is an absolute must in our system, where the guiding, storage, power, transportation, and method of movement or control are all important components that all must synergize to create an efficient system. We, as a team, consistently discussed the design specification and tried to tie that aspect to our subfunctions. Each one has an important purpose and several constraints that must be taken into consideration. For example, the collection aspect must be portable to allow for ease of use, be a universal interface with any type of mesquite tree and must be able to handle a lot of abuse. With these key factors in mind, we considered that agriculture already has several solutions that we can investigate, such as retractable olive picker tarps with a hopper at the bottom for storage. Or massive tarp systems that go across a grove and as the trees are excited, they are easily dropped into a tarp with ease.

Each of these ideas are possible solutions where we can step back and further understand where the pains of the mesquite farmer are and try to fix that. Below is the morphological chart for collection.

Sub-Functions	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Guiding Beans	Retractable Tarp	Hopper	Adjustable Buttons	Retractable Poppy Tarp	Adjustable Zipper Tarp	180° Tarp
Storage	Bins	Funnel	Bag/Elastic	Flat Gatherer	Vacuum	
Power	Human Interaction	Coded Using Arduino	Battery	Motor		
Method of Movement/ Control of Beans	Conveyer Belt	Manual Sweeping	Bristle Brush	User Control Interface	Pipe/Chute	
Transportation	Wheels	Human Interaction	Vehicle Mount/Hitch			

Table 3: Morphological Chart - Collection

Since all these designs are based on previously done projects, we can consider our project to be component design. We decided that it would not make sense to recreate the wheel and come up with a novel design and we looked towards what we know already works. Agriculture machines have been incredibly helpful in our design choices. We worked through every single solution that we added and weighed the pros and the cons of each, and we can say with confidence that we can decide what will work and will not work. However, there is one caveat. Our main design for the collection cannot be decided until the excitation aspect is completely understood and figured out.

3.3.2 Subfunction Charts

Subfunction charts are created specifically to compare different solutions of a subfunction to each other with either quantitative or qualitative criteria. Subfunction charts break down each solution and deliver more detailed information on each solution so that the solution is evaluated as an effective solution or not.

3.3.2.1 Excitation

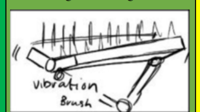
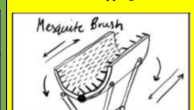
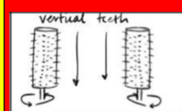
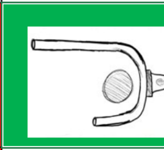
Sub Function 1: Branch Interface	Adjustable Clamp Branch Interface 	Immovable Fork Interface 	90 Degree Rotating Brush 	Horizontal Cupping Brush 	Vertical Rotating Column Brushes 	
Ease of Use	Good for both trunks and branches	Movable to the different Branches	Good for the ends of branches not for exciting the trunk	Diameters of Branches are inconsistant	Need heavy tractor attachments	creates minimal work for user.
Cost	Some sort of Steel would have to be considered. Nuts and Bolts, Hinges, and Electronics to control grabber movement.	The fork clamp would be made of steel.	A polymer of some sort, the bristles would be a semi-flexible. Steel parts to ensure maximum durability.	A polymer of some sort, the bristles would be a semi-flexible. Steel parts to ensure maximum durability.	Heavy machinery, Steel Parts, Polymer Bristles, but High volume of material used. Incredibly expensive.	cost effiective, using aluminum will allow for the hook to be low maitnance and inexpensive
Maneuverability	Needs to able to attach and detach easily from the tree	Has to be within the canopy	Has to get within the canopy of the tree to get to the branches with beans	Has to get within the canopy of the tree to get to the branches with beans	Hard for non-uniform trees	can attatch to various branch sizes with minimal effort. can be manuvered easily through canopy of the tree
Safety	Would be safe for both trunks and branches	may damange the tree if not padded correctly	relatively safe, can be used on perimeter of tree to shake down bean pods	may damage the branches	makes the beans into projectiles which will create a safety hazard	relatively safe, may cause slight tree damage over time if not padded
Conclusion	can be adjustible to both the trunk and branches and can be attached to multiple ideas. Multiple diameters	can damage the tree with the impact. Not a lot of room for impact space for how the branches grow.	only will hit the beans and leaves and not hit the branches themselves	is time consuming but is something that is faster than hand picking. Can damange the tree	B/c of the random alignment of the trees this would not work. Not an orchid layout.	Requires the least amount of work and can create branch interface required

Table 4: Subfunction Chart - Branch Interface

The first subfunction is Branch Interface. The Branch Interface requires connection between the machine and the branch to allow for constant vibration. This subfunction is comparing all its solutions to the following criteria: Ease of Use, Cost, Mobility, and Safety. The Adjustable Clamp falls in line with the criteria, but it would be more expensive with the extra parts to make the clamp adjustable. The Immovable Fork follows the criteria, but it could damage the tree without proper damping. The Vibrating Brush is a good design, but it is impractical because it cannot have any interface with the tree branches. This will create a decrease in the ease of use criteria. The Hook follows the criteria and would be less expensive, seeing as how it is less complex.

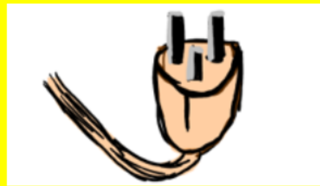
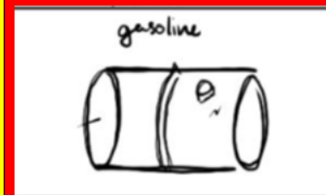
	Sub Function 2: Power supply		
Sub Function 2: Power Supply	Battery 	Electrical Input 	Gasoline/Fuel Powered 
Ease of Use	rechargable, longlasting, and replacable. good for both a single or multiple motor system	Need an external outlet and electrical source. Restrictions cause by cord length.	High Cost and high emission (not enviromentally friendly)
Cost	car battery	will be connected to electronics so no additional cost	will change with the changing gas prices and might not be the most cost efficent
Maneuverability	heavy, howvwer can be portable and able to carry back up battery.	low Maneuverability, cords can create limitations. Needs to be weather proof with long extensions.	will need a tank
Safety	can be recharged but if dropped due to being heavy and can cause bodily harm	Electrical circuts are relatively safe. may short circuit or cause electricution if not handled properly.	flammable
Conclusion	best for rotation of batteries to continue to work on trees while others charge	Inconvenient when working on a ranch and outlets are unaccessable. Relies on external battery source.	overall, not suitable for system due to high cost

Table 5: Subfunction Chart - Power Supply

The second subfunction is the Power Supply. Its solutions will be compared using the following criteria: Ease of Use, Cost, Maneuverability, and Safety. Using a Battery would maximize each of the criteria, seeing as how it can be replaced easily. Although the battery will increase the weight of the machine, the battery can be recharged, and multiple batteries can be made to effectively keep continuous production. Electrical Input follows some of the criteria, such that the cost is less expensive. However, electrical input would be inconvenient when being used on a ranch without outlets being readily available. Having the machine Gasoline/Fuel-Powered is not a suitable solution for Power. It is too expensive and unsafe.

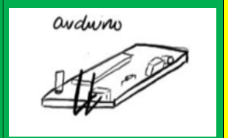
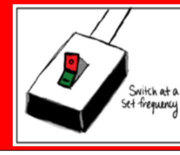
	Sub Function 3: Control				
Sub Function 3: Control	Adjustable Knob	Coded Through Arduino	Trigger	Power Switch	User Control Interface
					
Ease of Use	needed for a range of frequencies	can be used as a brain to control direction of multiple motor or gears system.	throttel of intensity of the frequency	will not be a set frequency	a combination of other controls with a larger interface. More for a tractor attachment
Cost	Not expensive, $20+ for a knob. Casing would have to withstand heat, and wear and tear. Possibly a low grade steel.	Arduino: already have 3 kits but if any other pieces need to be bought that will be at a higher cost	Trigger switches tend to be $20+	Not expensive, $20+ for a switch. Casing would have to withstand heat, and wear and tear. Possibly a low grade steel.	Expensive to create, implementing all of the electronics. A possible aluminum alloy for structure.
Maneuverability	can be attached to handheld piece and or user control interface	small, compact. easy to hide and attatch to system.	can be attached to a handheld piece	can be attached to handheld piece and or user control interface	not very moible unless attached to the tractor
Safety	user can control the intensity by visually seeing the need	if it gets wet might short circuit	user can control the intensity by visually seeing the need	if only one high intensiry the machine will not get a chance to cool off and work properly	may get confusing with all of the controls
Conclusion	best for handheld and for different frequencies	has the capibility to program system to switch between more than one motor or frequencies	best for handheld and for different frequencies	is good for handheld but not good for a range or frequencies	might be bulky and not moble enough but can have a larger combination of controls

Table 6: Subfunction Chart - Control

The third subfunction is Control. This subfunction is essential for both holding the vibration frequency and for connecting the machine together. Its solutions will be compared using the following criteria: Ease of Use, Cost, Maneuverability, and Safety. The Adjustable Knob is the best for handheld frequencies, given that it will keep the frequency for a prolonged amount of time without variation. The user can visually see what frequency is used. A Trigger control limits the range of frequency to one frequency. If the user has a heavy finger, the vibrations would not be constant. The Power Switch would limit the frequency to one range. All of these can be controlled through Arduino. A User Control Interface would be too bulky and heavy to maneuver around the ranch.

	Sub Function 4: Motor				
Sub Function 4: Motor	DC Electric Motor 	Servo Motor 	Offset Mass Motor 	Reciprocating Motor 	Cylinder Coreless Motor 
Frequency Range	has a very high frequency range that is determined by the size	can go up to 50 hz	typically used for small range frequency	Frequency range depends on overall size of the motor	not strong enough to hit the right frequency
Size	both compact and large depending on whats needed	compact but strong	compact and typically sized to fit into pagers and phones.	can be compact if low frequency is needed	small and may not be strong enough
Programmability	easy to control with arduino	can be programmed by arduino	easy to program but difficulty to set to a percise frequency.	easy to program to operate at differeent speeds and frequencies	easy to program to operate
Conclusion	easy to program and can hit the frequencies needed and is compact for attaching to electronics	easy to program and can hit the frequencies needed and is compact for attaching to electronics	easy to program and is compact for attaching to electronics but cant hit the frequencies needed	easy to program and can hit the frequencies needed but can be too big for a hand held device	easy to program and is compact for attaching to electronics but cant hit the frequencies needed

Table 7: Subfunction Chart - Motor

The fourth subfunction is the Motor. Its solutions will be compared using the following criteria: Frequency Range, Size, and Programmability. Any of these motors could serve the same purpose. However, the offset mass motor can offer an easier means of creating vibration, such that the offset mass can be changed and altered for changes in the frequencies.

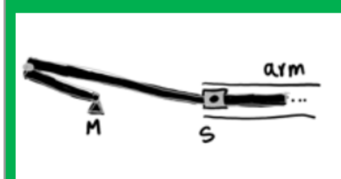
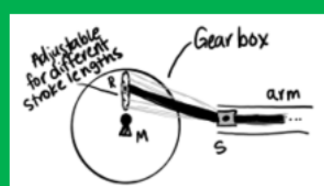
Sub Function 5: Method of Vibration	Slider Crank Method 	Slider Crank Method (Adjustable) 	Unbalanced Mass-Spring-Damper System 
Ease of Use	easily transmit power and roataion.	easily transmit power and roataion.	can be hard to replace parts if it were to break
Maneuverability	easily promgrammed to alter in speed; has set stoke length, can fit into handheld devices such as a sawzall	easily promgrammed to alter in speed, can fit into handheld devices such as a sawzall	complex to program a percise frequency.
Conclusion	Has a set stroke length and can change rpms allowing various frequencies to be reached	Can provide interchangeable strokelengths and various speed settings allowing for a range of frequencies to be reached	overcomplicating the function of creating vibration

Table 8: Subfunction Chart - Method of Vibration

The fifth subfunction is Method of Vibration. This subfunction is important because different mechanisms have different variables that are considered. The method that is applied will also affect the target vibration modes. Its solutions will be compared using the following criteria: Ease of Use and Maneuverability. The slider-crank methods can easily be maneuvered and designed. However, there is an increase in moving parts, which could create potential problems in the effectiveness of the machine.

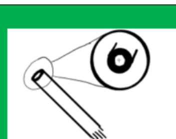
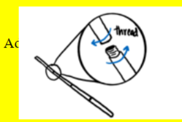
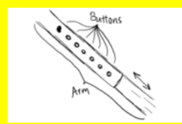
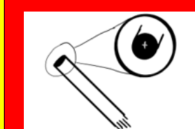
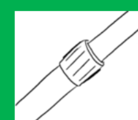
Sub Function 6: Arm Extension		Ac  ed			
weight	Not very heavy, depending on the material being used	Adjustable arm length with attatchable parts. Can easily be screwed on to desired length	Adjustable arm length with a clip/button system.	Too Heavy	Not very heavy, depending on the material being used
Cost	cost effective - depends on material	will have to manufacture threading ourselves	cost effective - depends on material	cost effective - depends on material	cost effective - depends on material
Maneuverability	has a set length, may reach high branches or may be difficult to manipulate lower branches	multiple rod segments can be lost or damaged. Carrying all segments may become overbearing	easy to clip in and out of length needed and will be durable enough to stay at length needed	Not as maneuverable because of the weight	the pieces that create length are within the biggest piece
Safety	can bend and tilt if the angle is too much	eacy to screw everything in place	when pushing the button the telescoping rod may fall all the way through	Weight could cause injury	easy to screw everything in place
Conclusion	can work for both protecting wires that may need to run the length of the rod but can't retract to be more moble	will be bad to move all the pieces around after colapsing the rod	strong and durable to have multiple lengths	Not as applicable as the hollow	can grow to the length needed and can be easliy brought up and down

Table 9: Subfunction Chart - Arm Extension

The sixth subfunction is Arm Extension. This subfunction allows the machine to reach into the higher points of the tree. Its solutions are evaluated with the following criteria: Weight, Cost, Maneuverability, and Safety. The Hollow Pole allows the machine to be less heavy, but it cannot be extended or retracted for different tree heights. The Threaded Pole Parts allows for easy extension and retraction of the arm. However, there are too many parts in this design, and it would develop too many weak points within the arm. The Pin-Fastened Pole would allow for retraction and extension, but it could result in the failure of the pins which could compromise the safety of this machine. A Solid Pole would not allow for inputting wires, which is necessary to do for the machine. A Telescoping Arm could extend and retract in length easily.

3.3.2.2 Collection

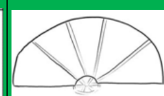
SubFunction	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Guiding Beans						
Ease of Use	Wraps around tree, easy to manipulate, however, has a fixed tarp diameter.	On Wheels, can be rolled under the tree.	Enough coverage, can be rotated and collapsed.	Adjustable Diameter, adjusts for different canopy diameters.	Adjustable Diameter, adjusts for different canopy diameters.	Adjustable Diameter, adjusts for different canopy diameters.
Cost	Aluminum Brackets, Tarp, and Nuts and bolts. Relatively inexpensive.	Aluminum Hopper, needs to be manufactured or puchased from a third party source. (Graingor or Harbor Freight)	about the same at the retractable tarp.	Aluminum Brackets, Buttons, Tarp, Nuts and Bolts, Relatively Inexpensive.	Aluminum Brackets, Tarp, and Nuts & Bolts. Relatively Inexpensive	Aluminum Brackets, Zippers, Tarp, Nuts and Bolts, Relatively Inexpensive.
Maneuverability	Depending on the tree can be hard to unfold under the tree.	Manually needs to be moved under the tree.	if collapsed, maneuverability can increase.	Manually needs to be buttoned up by the user, takes time to do.	Manually needs to be placed and expanded or be moved mechanically.	Manually needs to be zipped up by the user, takes time to do.
Safety	Removes the need to go under the tree to collect, removes thorn hazard.	Removes the need to go under the tree to collect, removes thorn hazard.	large range of motion can injure the unaware.	Removes the need to go under the tree to collect, removes thorn hazard.	Removes the need to go under the tree to collect, removes thorn hazard.	Removes the need to go under the tree to collect, removes thorn hazard.
Conclusion	Can be designed manually or automatically and can ideally go under the entirety of the tree.	A variation is needed for the hopper and needs to be combined with the tarp in some way, since having a single hopper under a tree is inefficient.	can be designed manually, and can be rotated for maximum range of motion.	Beans can fall into the the grooves/ flaps can be changed for velcro.	Will be a complex kinematic design, and with our given time span, would not be suitable.	Can be excessive with the amount of zippers needed to expand them correctly.

Table 10: Subfunction Chart - Guiding Beans

The first subfunction is Guiding Beans. Guiding the beans requires that there is a location for beans to fall and allows for the guidance of the beans to the next step of the process. Its solutions will be evaluated through the following criteria: Ease of Use, Cost, Maneuverability, and Safety. The Retractable Tarp, Hopper, and 180 Degree Tarp are the top solutions because they follow the criteria for their subfunction. They can be implemented and integrated within each other. The last three solutions follow some of the criteria, however, they all have critical design nuances that affect the practicality of the design (i.e. the beans can fall between the gaps for the buttons, the zippers would add too much weight, etc.).

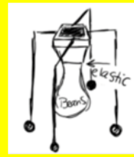
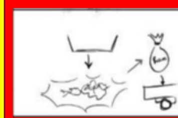
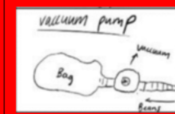
SubFunction	Solution 1	Solution 2	Solution 3	Solution 4	
Storage					
Ease of Use	Easily attatched to the end of the vibration brush, integration between excitation and collection.	A bag can be attatched using an elastic band, can be easily attatched and removed once filled.	Can be constantly changed out. Probably more labor intensive with lifting.	Labor-intensive, the bag would have to be large enough to catch almost all of the beans, gathering the beans will not minimize the material being used.	Easy to use. Would run along the trees to simulate wind. However, the beans would probably fly in different ways, causing them to be much harder to collect.
Cost	The hopper attachment may be created using a polymer of some sort that can handle the sharp points. Price varies on material.	Bag Material may be more costly versus burlap, since we need to account for the sharp point on bean pods.	Typical Trash cans made out of a polymer. Could be the barrels that the Cappadona's have already. Little to No cost.	Could become very expensive because of the constant changing of the plastic bag.	Not too expensive, about the same cost as a high-grade vaccum. Shop-Vac, etc.
Maneuverability	May have issues manuvering the bin with the attachment. The offset mass may be too overbearing for the user.	Bag is detatched and carried manually by user. Transported to a vehicle for sorting process.	Could become very heavy with all of the beans collected. Could be difficult to lift.	This would probably not be put all the way around the tree, only specific sections of the tree. The material would have to withstand various environments because it will be laid on the ground of the ranch.	Reduces the need for being underneath the tree. A series of piping and suction through a displacement. The beans could get stuck in the piping, as well as small animals, leaves, etc.
Safety	Removes the user's physical interaction with the bean to drop into a hopper. User is not harmed by the process.	Lifting the heavy bags could cause injury if done incorrectly, however the beans will be transported efficiently.	Safety would probably be maximized. However, lifting the heavy barrels could cause injury if done incorrectly.	The workers would have to go underneath the tree and risk their safety because of the thorns and overgrowth under the trees.	Safety would probably be maximized. However, it runs the risk of having 'backups'.
Conclusion	The hopper may be top-heavy, but the process can be integrated in another fashion to minimize cost and maximize safety.	Reloadable bags minimized reload time and leads to an easier method of transporting beans to the sifting process versus collections into a barrel.	The barrels would minimize the cost of the project. However, this will not make the task of transporting beans easier.	This process is labor-intensive and is cost-heavy.	Too much uncertainty with collecting the beans and the overall function of the machine could be compromised.

Table 11: Subfunction Chart - Storage

The second subfunction is Storage. Storage of the beans is the final step of the system. With the guidance of the bean to the storage selection, the beans reach their destination where the user can use the beans for the next step of their manufacturing process. Its solutions are evaluated with the following criteria: Ease of Use, Cost, Maneuverability, and Safety. The most practical solution is to design a system in which reusable bins can be implemented for easy storage replaceability. The two yellow solutions follow some criteria, but they would be unsuitable for ranch terrain. The tarp on the floor (Solution 4) would not do well with the various terrain of the ranch. Solution 5 is very inconsistent seeing as how blowing air into the trees can cause the beans to fly in various directions. Sucking the beans with a vacuum pump could cause potential damage to any pump because of the beans' geometries.

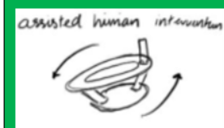
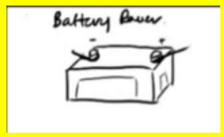
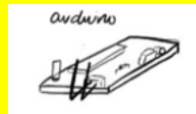
SubFunction	Solution 1	Solution 2	Solution 3	Solution 4
Power				
Ease of Use	Manual labor, more labor-intensive than the other solutions.	Easier to integrate into the project. Ability to recharge and apply voltages.	Coding is necessary for production. Would probably need a smaller battery.	Would have to be highly integrated with the excitation machine. Would take a lot of energy.
Cost	Little to no cost unless it is made in a way that it can be used much easily.	Cost of a car battery.	$80+	High Cost with material and gasoline.
Maneuverability	A series of gears, cranks, pulleys, etc.	Easier to move around, smaller in size.	N/A	Heavy Machinery. Cannot be handheld.
Safety	Safe, unless used incorrectly.	Possible safety hazards when in contact with different weather conditions.	Possible safety hazards when in contact with different weather conditions.	Could be dangerous. Flammability. Not to be used in many weather conditions.
Conclusion	Safe for use and completes the job, but it is more labor intensive.	Would have to be integrated with other aspects of the project for implementation.	Would have to be integrated with other aspects of the project for implementation.	A high-cost machine, that is not easy to maneuver.

Table 12: Subfunction Chart - Power

The third subfunction is Power. Its solutions are evaluated with the following criteria: Ease of Use, Cost, Maneuverability, and Safety. Assisted Human Interface is the most effective solution. However, this can also be replaced by a battery-powered motor. Gasoline would be inefficient and expensive.

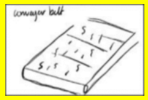
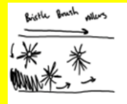
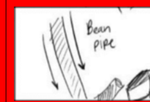
SubFunction	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Method of Movement/Control of Beans	None					
Ease of Use		Would be a retractable conveyor belt that can be mecanically retracted and pulled manually.	User does not physically touch the beans, but may be hard to stick the broom/brush in.	Removes the user from the equation, mechanically moves the beans through shafts and brushes. All done at the flip of a switch.	Would require training for the workers.	Runs the risk of getting the beans stuck within the piping. Prone to having the beans 'backup'.
Cost		Timely to manufacture, expensive due to motors, controls, and materials.	Extremely Inexpensive.	Expensive to make, requires motors and arduino to coordinate the shaft.	Expensive	Inexpensive.
Complexity		Requires K&D, knowledge of arduino related electronics, motors, machine elements, and geometry to get the right shape to work.	Not complex by any means, just requires a user with a broom.	Requires K&D, knowledge of arduino related electronics, and machine elements to control shaft rotation.	Complex in terms of electronics.	Not Complex. The material would have to withstand the sharp points of the mesquite beans.
Safety		Tarp runs along the ground, but serves as a barrier to the beans. Does not introduce contaminants to the beans.	Removes physical contact with beans (hand touching) but may introduce contaminants into the beans.	User isn't exposed to sharp bean pods, however would be incredibly unsafe for user to stick body parts in. Also small critters need to be considered.	Safe from poor weather conditions, but would not be very mobile.	Removes the need to go under the tree to collect, removes thorn hazard.
Conclusion		Could be a sufficient solution considering that the time and effort is put in to ensure optimal canopy coverage on the ground.	Extremely inexpensive, but may degrade the food, further research will be needed, but we'd like to avoid it if possible.	Could be used in ideal conditions, but may be difficult to manufacture, maintain, and may be costly.	Complex and Immobile. Would be expensive and require more attention.	Although inexpesive and safe, it would have obe integrated with another asepct of the project to work. The function of the pipe could be compromised.

Table 13: Subfunction Chart - Method of Movement/Control of Beans

The fourth subfunction is Method of Movement/Control of Beans. Its solutions are evaluated with the following criteria: Ease of Use, Cost, Complexity, and Safety. All but one solution has faults with the criteria. Having no method of movement for the beans relies mostly on gravity. This results in no cost, no usage, no complexity, and utmost safety.

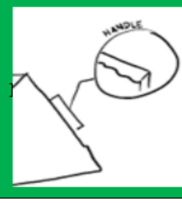
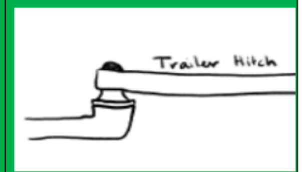
SubFunction	Solution 1	Solution 2	Solution 3
Transportation			
Ease of Use	Tires need to be big enough for the ranch terrain to not break	Can be grabbed to guild the machine to a new localized spot of the tree	Easy to attach and move from tree to tree
Cost	Depending on the size of wheels needed can get pricy	Easy to find at lowes	can be relatively expensive
Maneuverability	Helps moves over the ranch	will help move from location to location	helps move from tree to tree
Safety	if there is a flat can easliy be replaced	increases safety by having a hand hold to move the machine	can easily be removed and attached
Conclusion	needed to keep up with the ranch terrain and helps with mobilization	needed to help facilitate movement around the tree	can be expensive but is an neccessary investment to move along a large range of land

Table 14: Subfunction Chart - Transportation

The fifth subfunction is Transportation. Its solutions are evaluated with the following criteria: Ease of Use, Cost, Maneuverability, and Safety. All the solutions maximize the criteria, such that they increase the machines ease of use, have equal cost, increase maneuverability, and increase safety.

3.4 Conceptual Variants

3.4.1 Excitation

3.4.1.1 Analysis

Before deciding what conceptual variants can be created or chosen, an analysis is pertinent. An approach that we are taking is a vibrational approach while implementing the Finite Element Method. By getting a specific range of the sizes and shapes of the mesquite bean, we will be able to see exactly what the smallest and largest natural frequencies of the mesquite bean are that we can apply to the tree. With this range of frequencies, we will be able to figure out if we need a motor for smaller vibrations or if we need to move towards acoustic vibrations for larger frequencies. Knowing the mode of vibration will allow for one to determine the placement of the motor, if applicable.

3.4.1.2 Axial Vibration

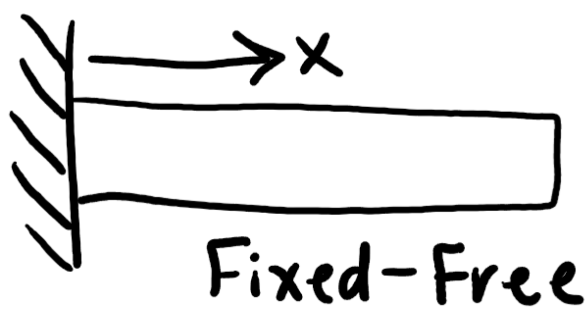


Figure 4: Axial

This method of vibration deforms along the central axis.

$$\omega_n = \frac{(2n-1)\pi\sqrt{\frac{E}{\rho}}}{2L}$$

Figure 5: Axial Sanity Check Equation

This equation is the natural frequency of the entity under axial vibration.

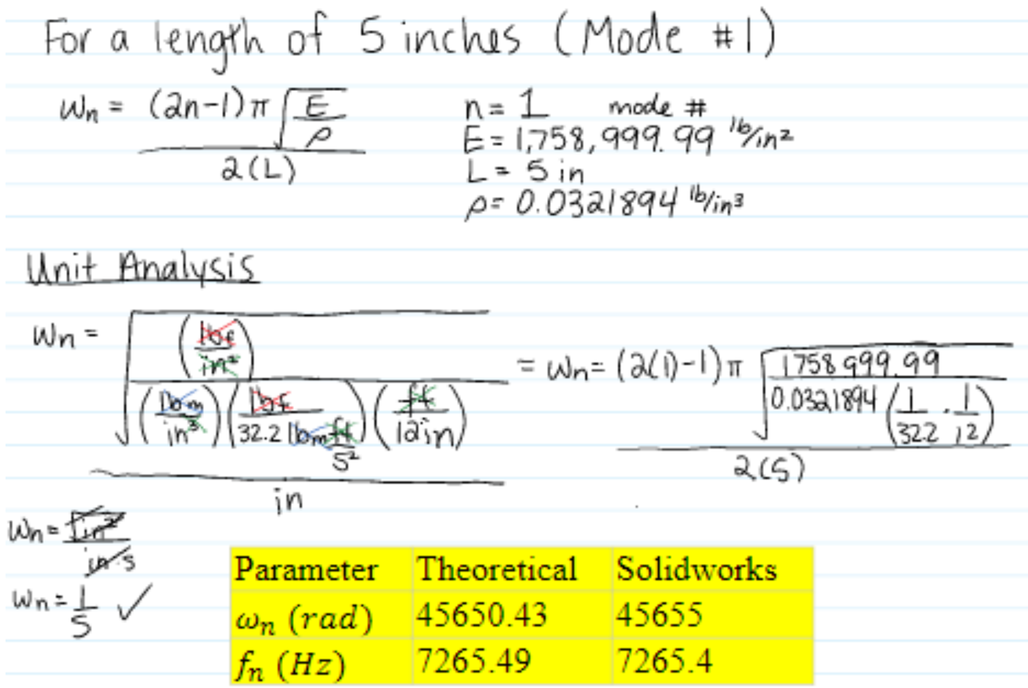
$$n = 1,2, \ldots$$

$$\sin\left(\frac{(2n-1)\pi x}{2L}\right)$$

Figure 6: Axial Mode Shape

This equation is the mode shape of the entity under axial vibration.

The following calculations are for the Axial Modes for a simple 5 in bean and a simple 7.25 in bean. The calculations are then compared to the values from SolidWorks. If the values are within range of each other than the SolidWorks checks out with the theoretical and more complex geometries can be made.



$$\omega_n = \frac{(2n-1)\pi\sqrt{\frac{E}{\rho}}}{2(L)}$$

$$\omega_n = \frac{(2(1)-1)\pi\sqrt{\frac{1758999.99}{0.0321894\left(\frac{1}{32.2}\cdot\frac{1}{12}\right)}}}{2(5)}$$

Parameter	Theoretical	Solidworks
ω_n (rad)	45650.43	45655
f_n (Hz)	7265.49	7265.4

Figure 7: Sanity Check For 5-inch Bean Axial

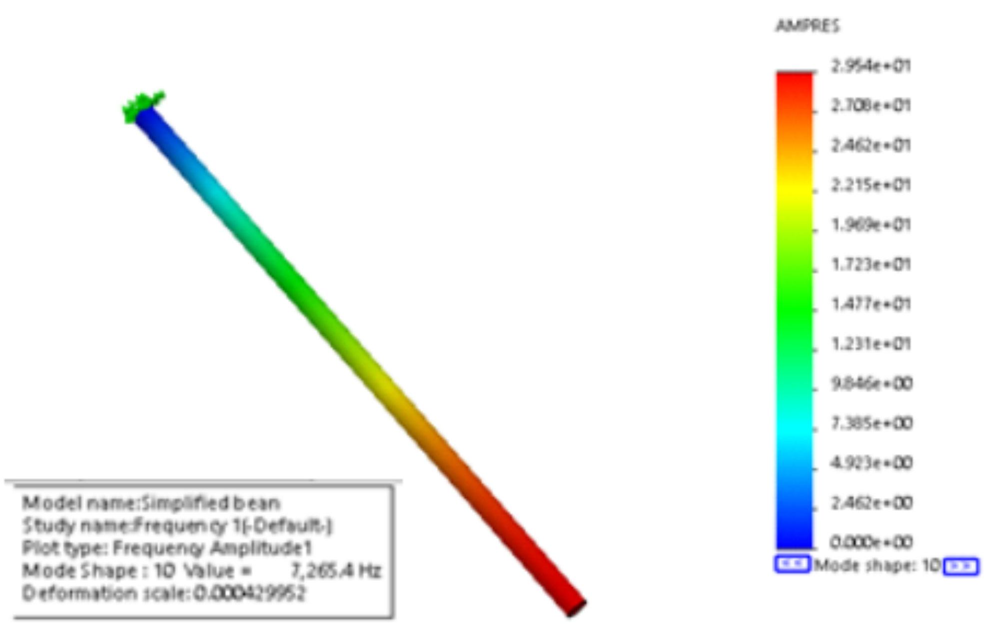


Figure 8: FEA Model Axial

For a length of 7.25 in (Mode 1)

$n = 1$

$E = 1{,}758{,}999.99 \ \mathrm{lb/in^2}$

$L = 7.25 \ \mathrm{in}$

$\rho = 0.0321894 \ \mathrm{lb/in^3}$

$$\omega_n = \frac{(2(1)-1)\pi \sqrt{\dfrac{1758999.99}{0.0321894\left(\dfrac{1}{322}\cdot\dfrac{1}{12}\right)}}}{2(7.25)}$$

Parameter	Theoretical	Solidworks
$\omega_n\ (rad)$	31483.06	31478.13
$f_n\ (Hz)$	5010.68	5009.9

Figure 9: Sanity Check for 7.25-inch Bean Axial

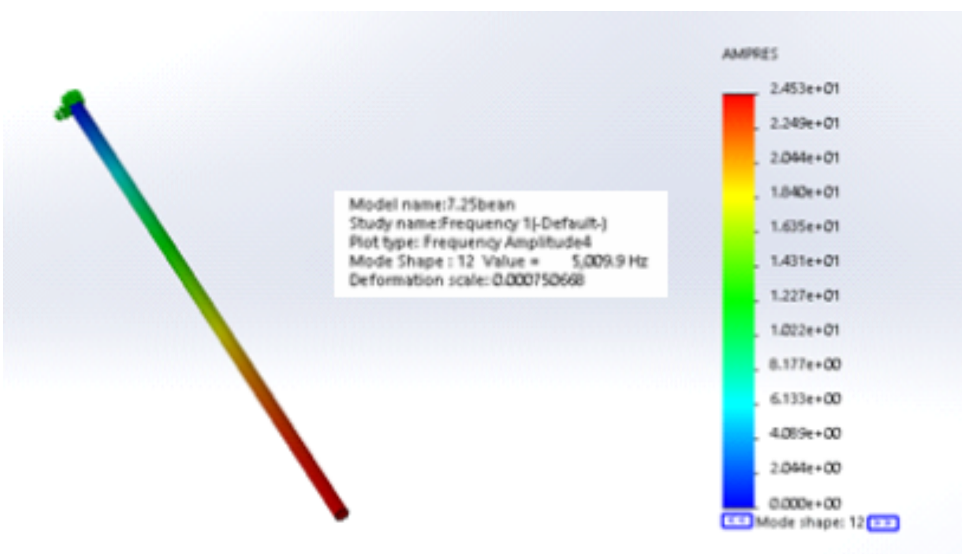


Figure 10: FEA Model Axial

3.4.1.3 Bending Vibration

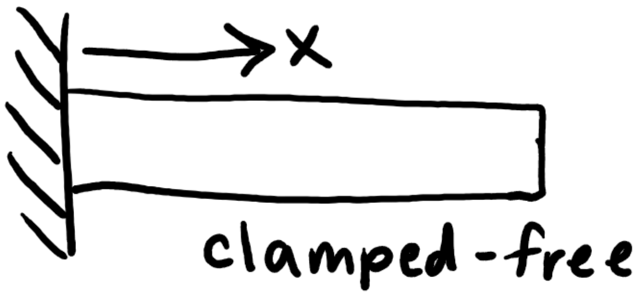


Figure 11: Bending

This method of vibration deforms along a plane perpendicular to central axis.

$$w_n = \beta_n^2 \sqrt{\frac{EI}{\rho A}}$$

$$\beta_1 L = 1.875104$$

$$\beta_2 L = 4.694091$$

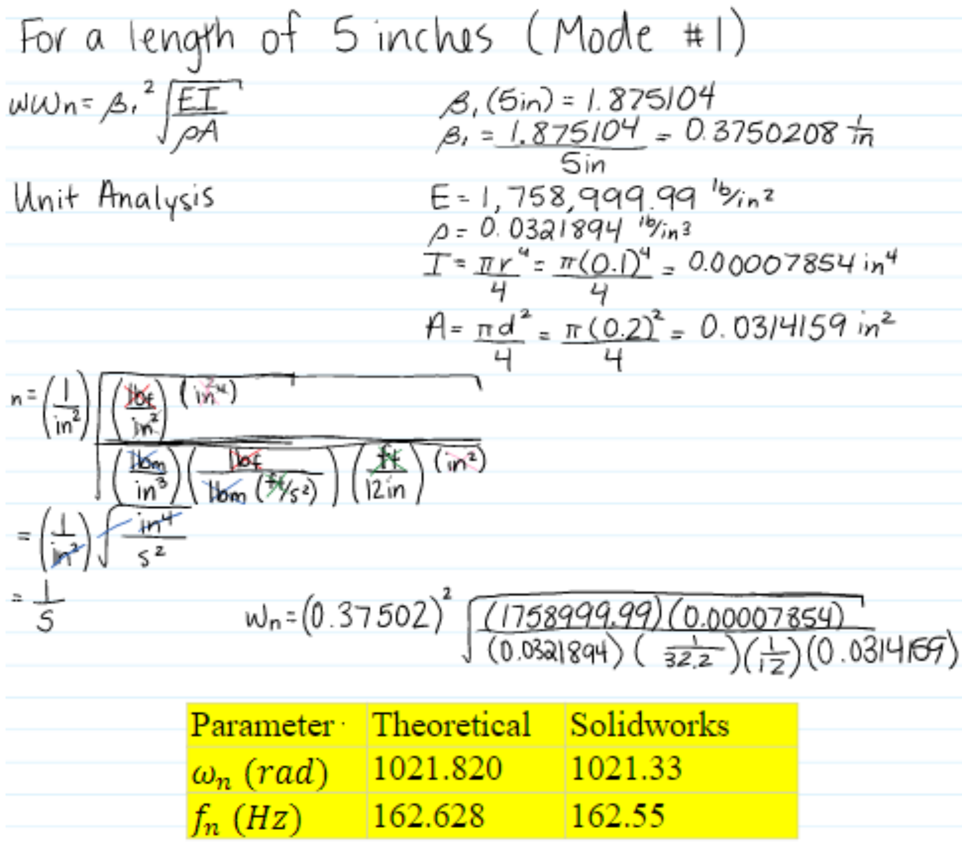
$$\beta_3 L = 7.854757$$

$$\beta_4 L = 10.99554$$

Figure 12: Equation for Bending

This equation is the natural frequency of the entity under bending vibration.

The following calculations are for the Bending Modes for a simple 5 in bean and a simple 7.25 in bean. The calculations are then compared to the values from SolidWorks. If the values are within range of each other than the SolidWorks checks out with the theoretical and more complex geometries can be made.



Parameter	Theoretical	Solidworks
$\omega_n\ (rad)$	1021.820	1021.33
$f_n\ (Hz)$	162.628	162.55

Figure 13: Sanity Check for 5-inch Bean Bending

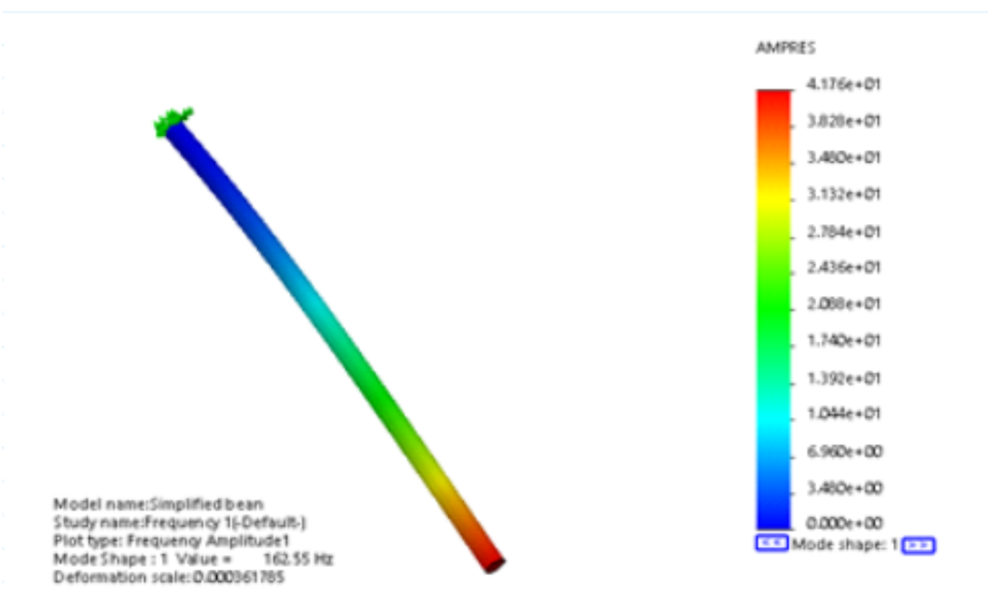
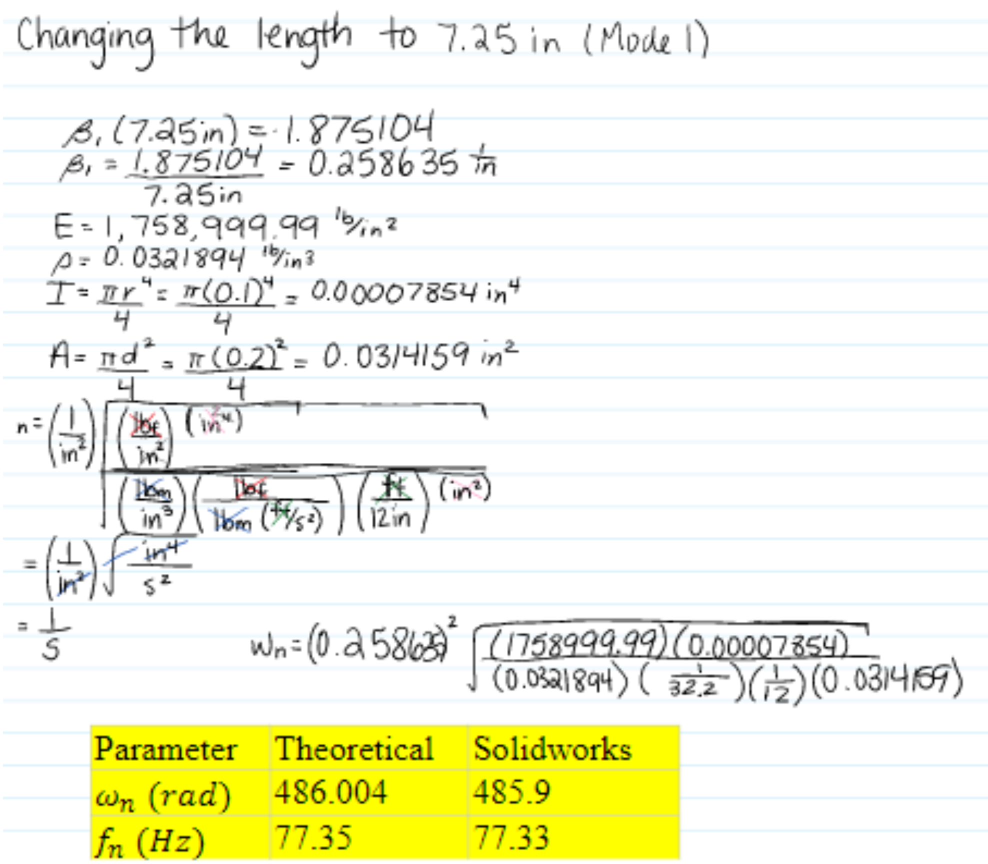


Figure 14: FEA Model Bending



Parameter	Theoretical	Solidworks
ω_n (rad)	486.004	485.9
f_n (Hz)	77.35	77.33

Figure 15: Sanity Check 7.25-inch Bean Bending

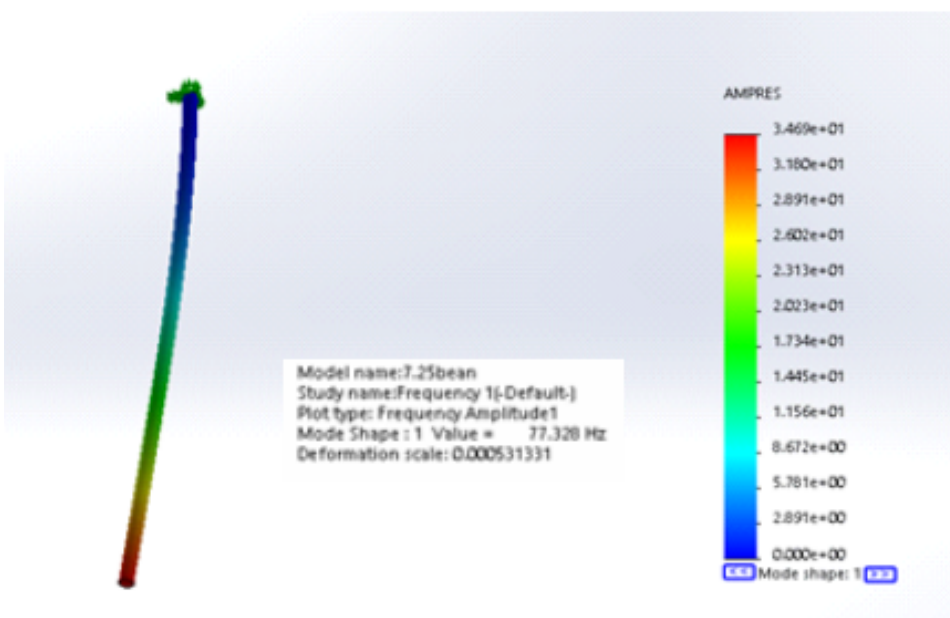


Figure 16: FEA Model Bending

3.4.1.4 Torsional Vibration

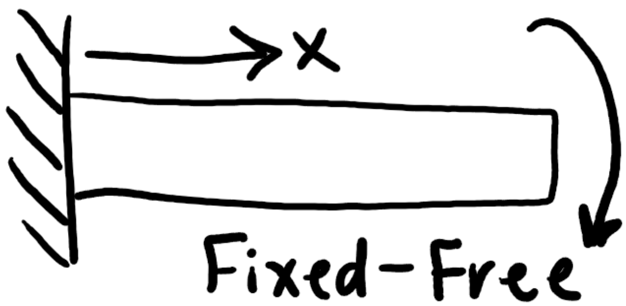


Figure 17: Torsional

This method of vibration deforms along the cross-sectional area of the entity.

$$\omega_n = \frac{(2n-1)\pi\sqrt{\frac{G\gamma}{\rho J}}}{2L}$$

Figure 18: Equation for Torsional

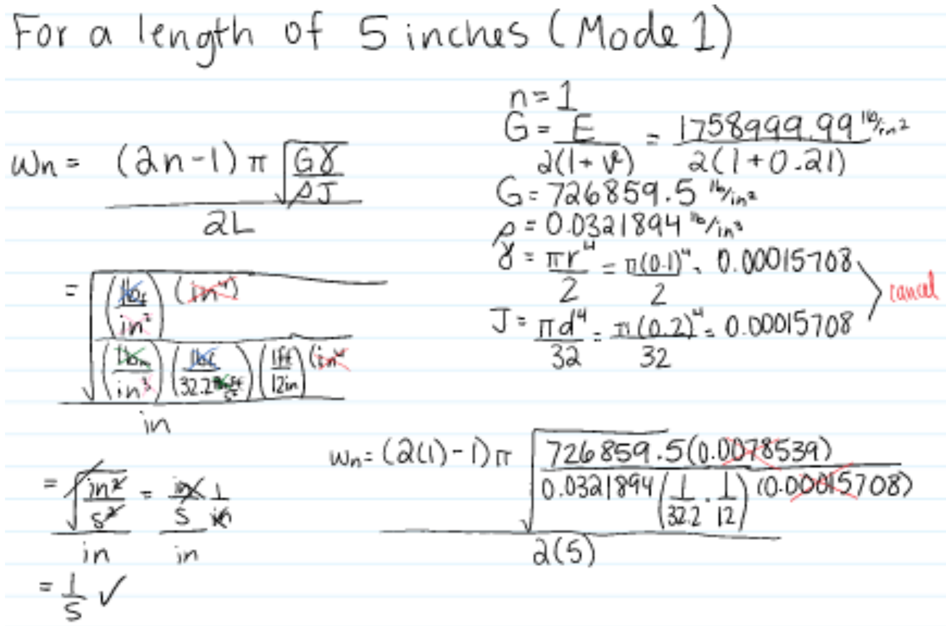
This equation is the natural frequency of the entity under torsional vibration.

$$n = 1,2,\ldots$$
$$\sin\left(\frac{(2n-1)\pi x}{2L}\right)$$

Figure 19: Equation for Mode Shape Torsional

This equation is the mode shape of the entity under torsional vibration.

The following calculations are for the Torsional Modes for a simple 5 in bean and a simple 7.25 in bean. The calculations are then compared to the values from SolidWorks. If the values are within range of each other than the SolidWorks checks out with the theoretical and more complex geometries can be made.



Parameter	Theoretical	Solidworks
ω_n (rad)	29345.4	28877.52
f_n (Hz)	4670.5	4596

Figure 20: Sanity Check for 5-inch Bean Torsion

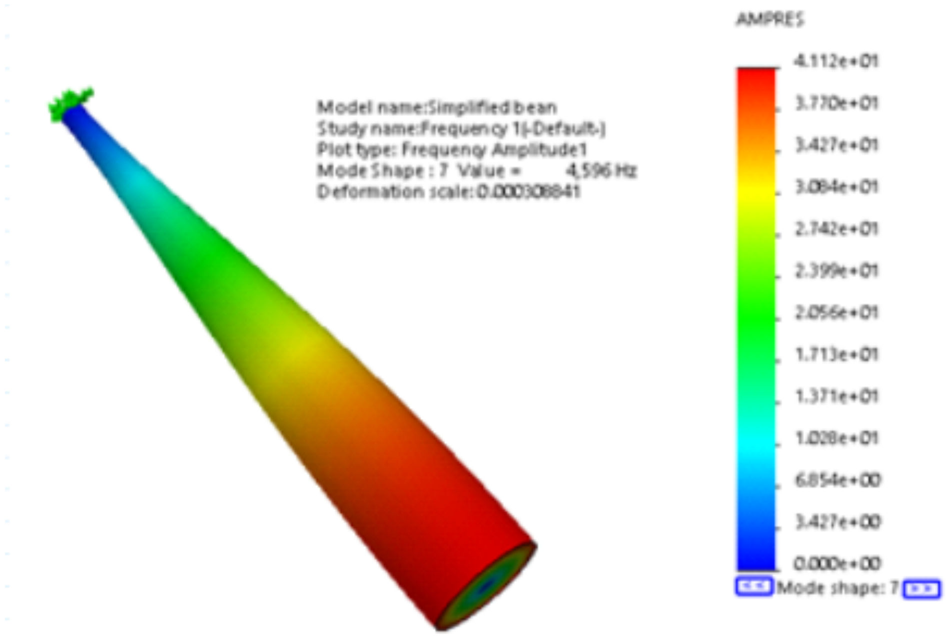


Figure 21: FEA Model Torsion

For a length of 7.25 inches (Mode1)

$n = 1$

$$G = \frac{E}{2(1+\nu)} = \frac{1758999.99 \ lb/in^2}{2(1+0.21)}$$

$$G = 726859.5 \ lb/in^2$$

$$\rho = 0.0321894 \ lb/in^3$$

$$\gamma = \frac{\pi r^4}{2} = \frac{\pi (0.1)^4}{2} =$$

$$J = \frac{\pi r^4}{2} = \frac{\pi (0.1)^4}{2} =$$

cancels

$$\omega_n = \frac{(2(1)-1)\pi \sqrt{\dfrac{726859.5}{0.0321894\left(\frac{1}{32.2}\cdot\frac{1}{12}\right)}}}{2(7.25)}$$

Parameter	Theoretical	Solidworks
ω_n (rad)	20238.20	19770.04
f_n (Hz)	3221.01	3146.5

Figure 22: Sanity Check 7.25-inch Bean Torsion

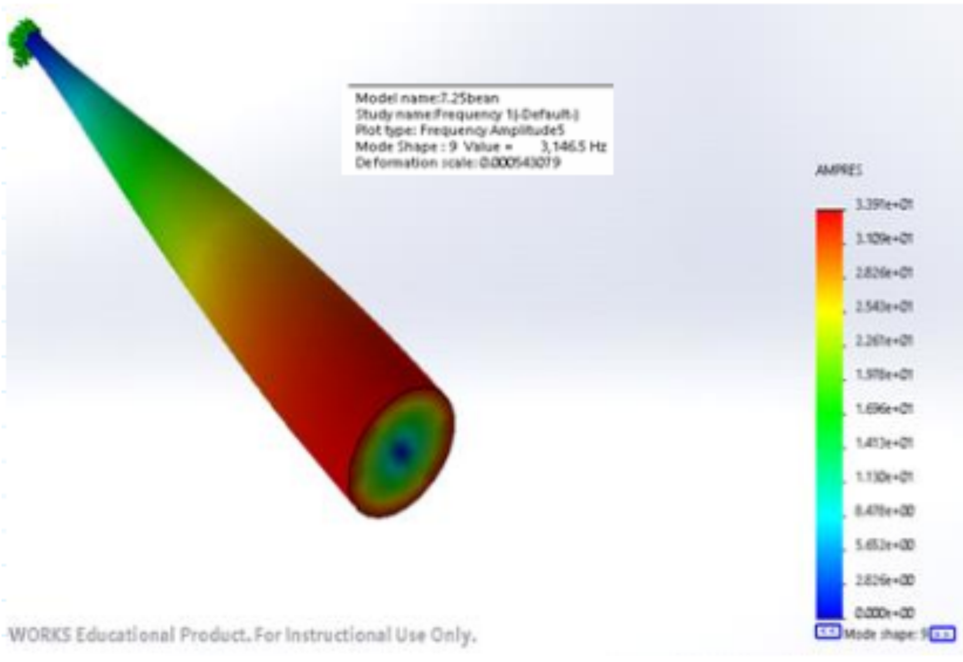


Figure 23: FEA Model Torsion

Because the calculations all checked out, more complex simulations were done.

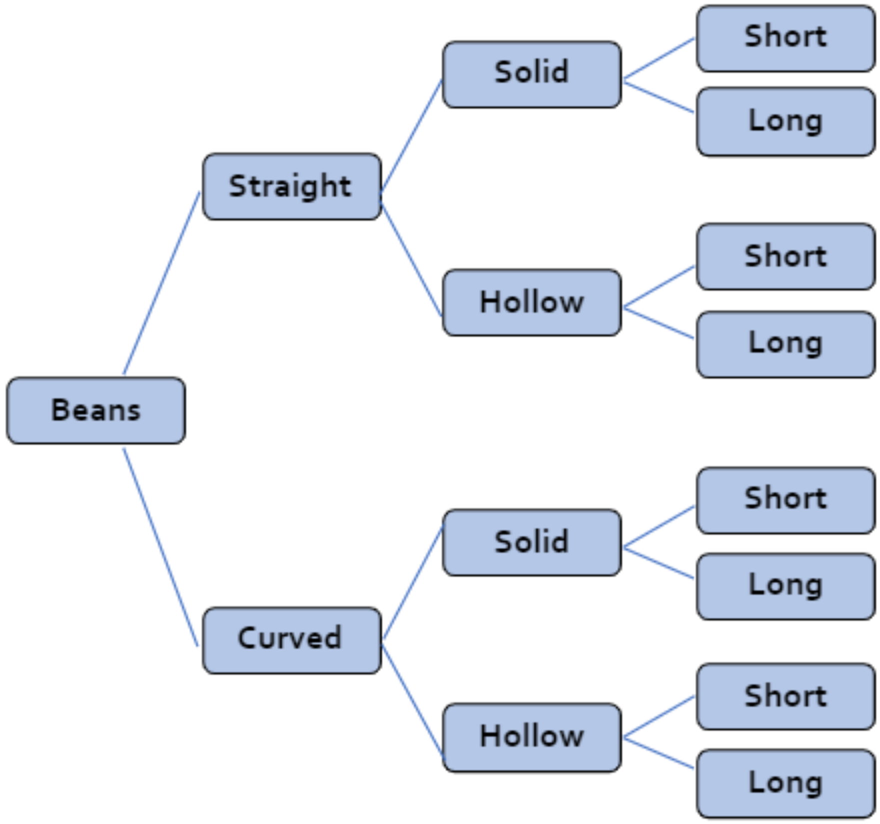
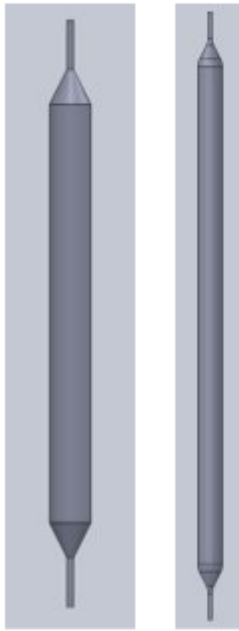
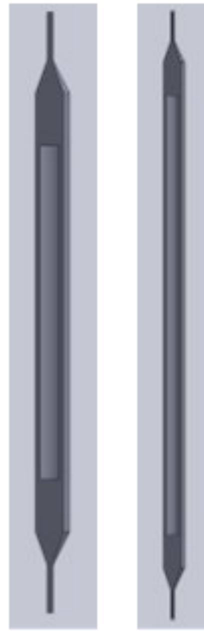


Figure 24: Breakdown of CAD Bean Complexity

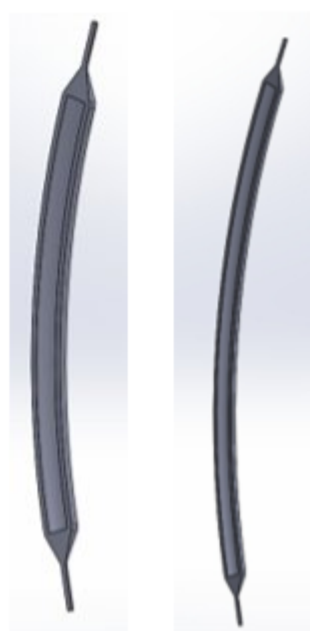


LEFT TO RIGHT: Short Bean, Long Bean. Solid, Straight.



LEFT TO RIGHT: Short Bean, Long Bean. Hollow Straight.

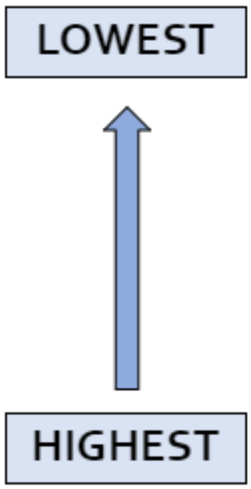
LEFT TO RIGHT: Short Bean, Long Bean. Solid, Curved.



LEFT TO RIGHT: Short Bean, Long Bean. Hollow, Curved.

Figures 25-28: Mesquite Bean CAD Models

These complex simulations where made to find a range of frequency needed to excite the beans.



Overall Frequency Range

Bending		
	Lower	Upper
ωn (rad/s)	50.5708	151.079
f (Hz)	**8.0486**	**24.045**

Torsional		
	Lower	Upper
ωn (rad/s)	679.966	2492.85
f (Hz)	**108.22**	**396.75**

Axial		
	Lower	Upper
ωn (rad/s)	8279.35	23256.6
f (Hz)	**1317.7**	**3701.4**

Table 15: Overall Frequency Ranges

Axial and Torsional Vibration are not suitable, given that their ranges fall closer to acoustic vibration.

Bending		
	LOWER	UPPER
ωn (rad/s)	50.5708	151.079
f (Hz)	8.0486	24.045
RPM	482.916	1442.7

Table 16: Prospective Method of Vibration

Bending Vibration is the prospective method of vibration on its own, given that it had the lowest range of frequencies, being from 8 Hertz – 24 Hertz. This range falls into the Mechanical Vibration aspect of the project, such that a motor can be utilized. The mesquite bean will reach resonance once its natural frequency is met and applied for a prolonged amount of time. Not only that, the curvature of bean could facilitate both bending and torsional vibration.

3.4.2 Excitation

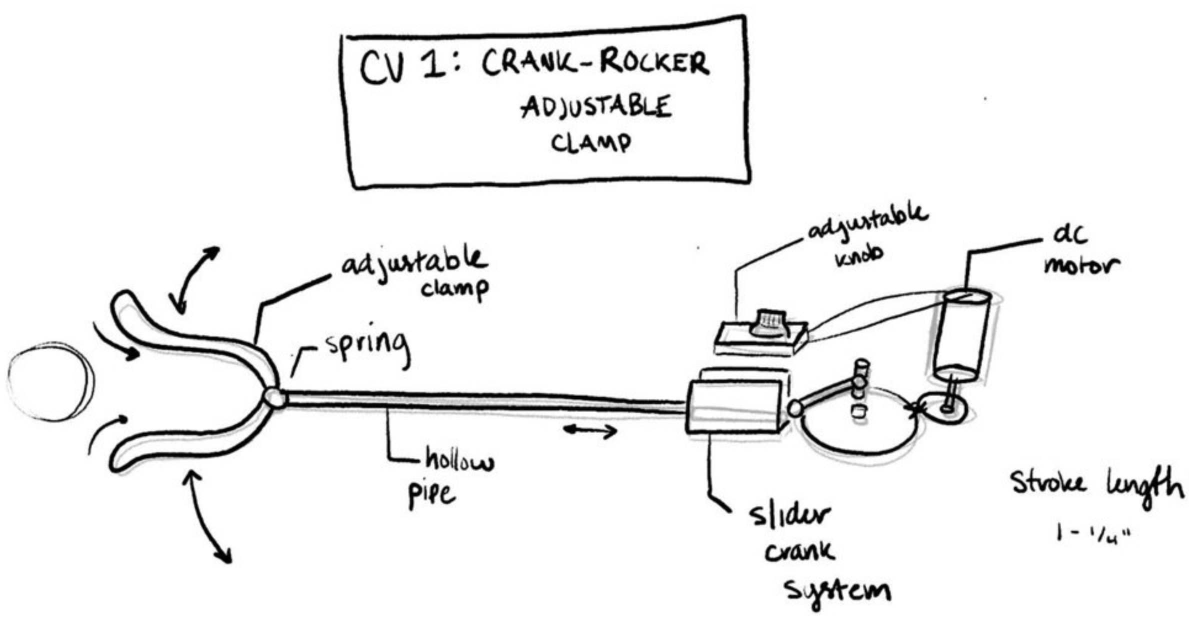


Figure 29: Spring-Loaded Clamp Slider-Crank – Adjustable Knob

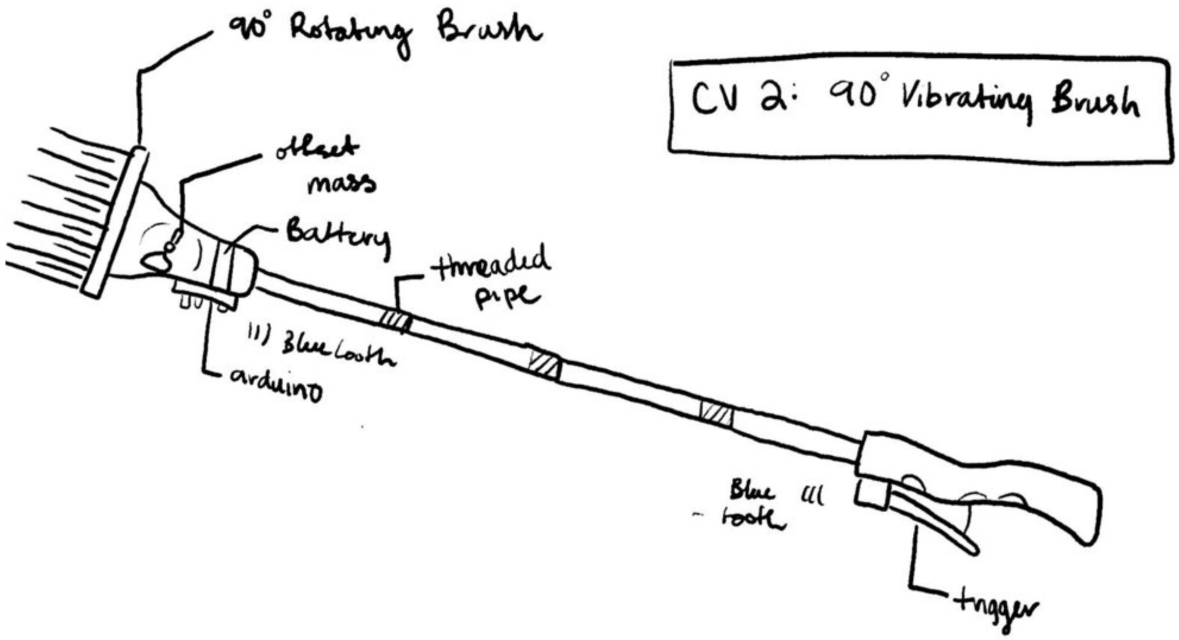


Figure 30: Offset Mass Generated Brush – Trigger

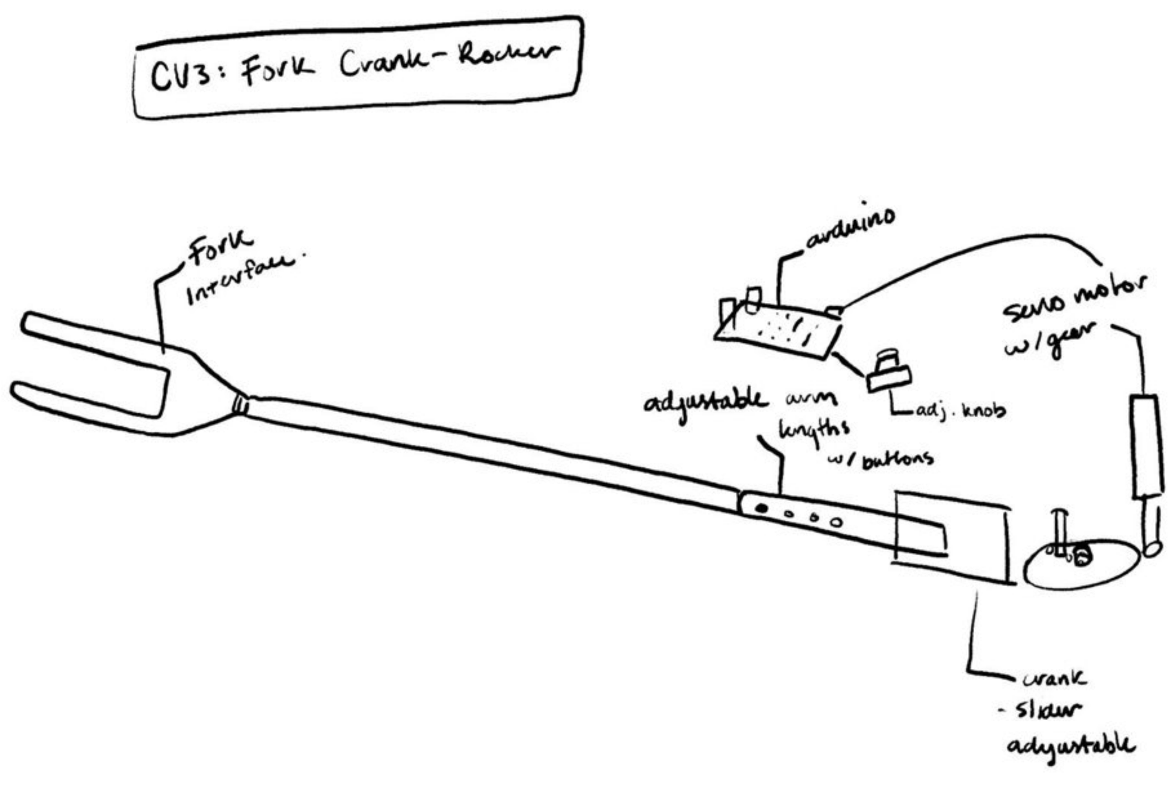


Figure 31: Immovable Fork Slider Crank – Bottom Heavy

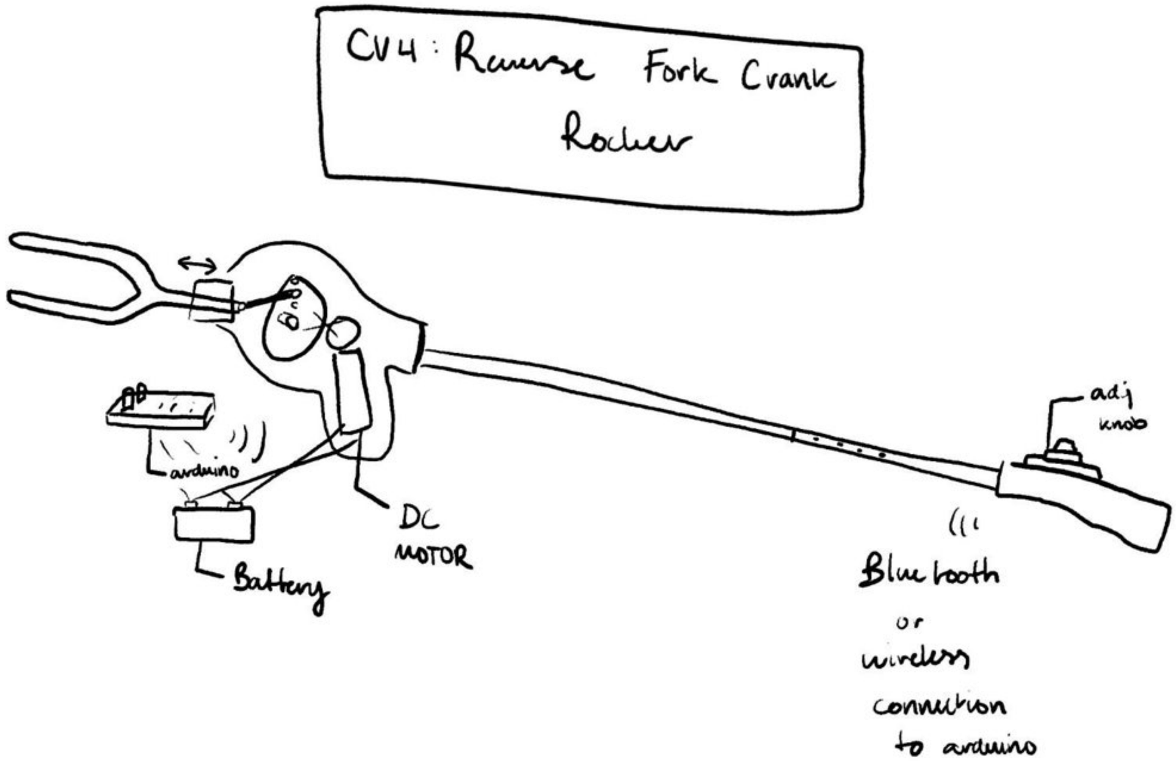


Figure 32: Immovable Fork Slider Crank – Top Heavy

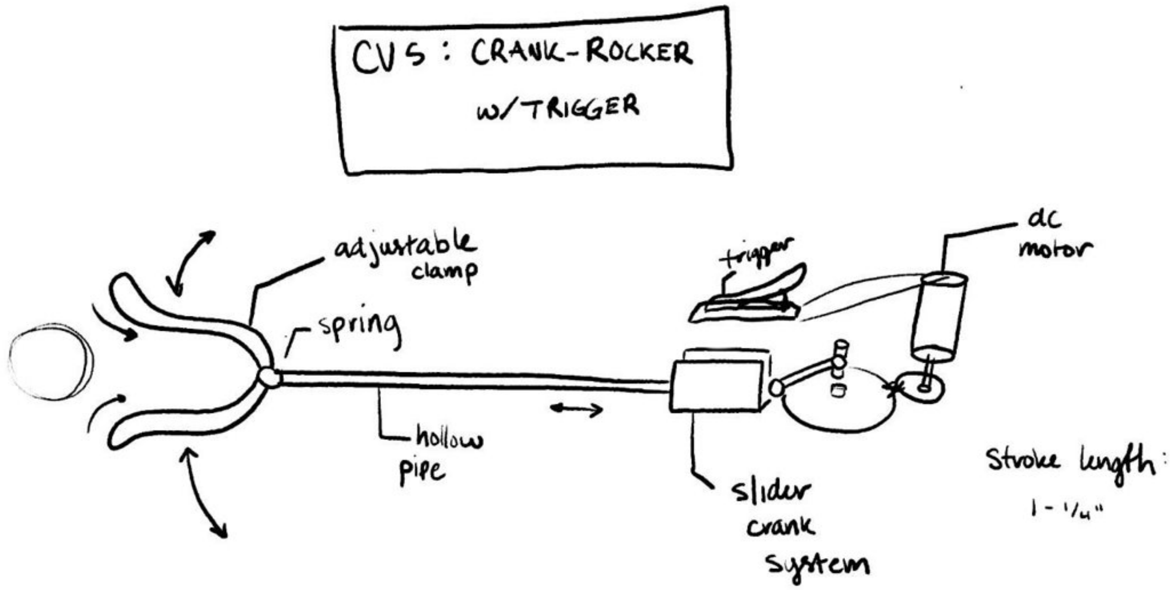


Figure 33: Spring Loaded Slider Crank – Trigger

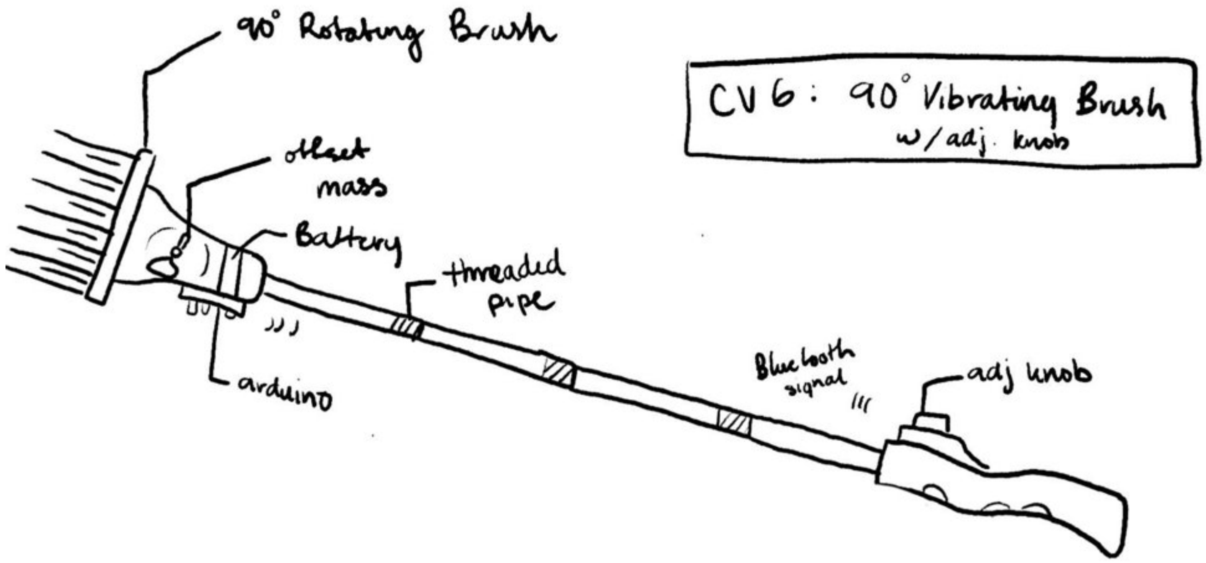


Figure 34: Offset Mass Generated Brush – Adjustable Knob

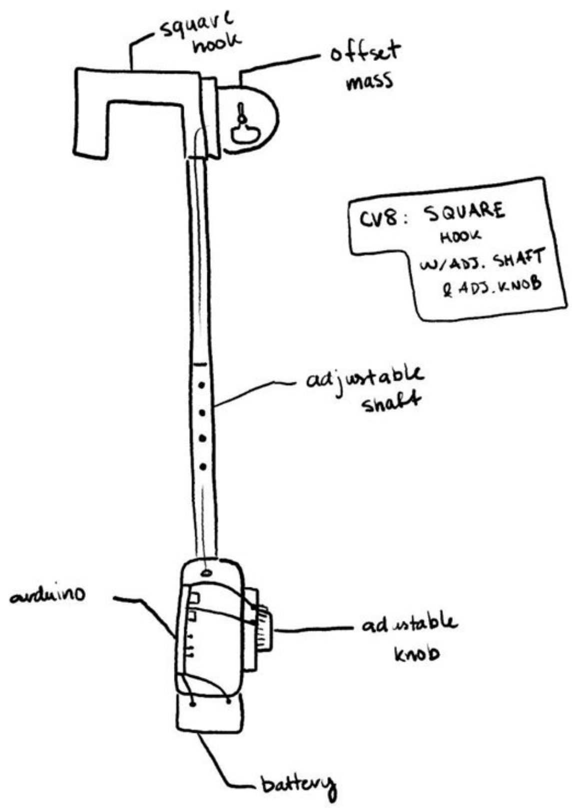


Figure 35: Hanging Square Hook – Adjustable Knob

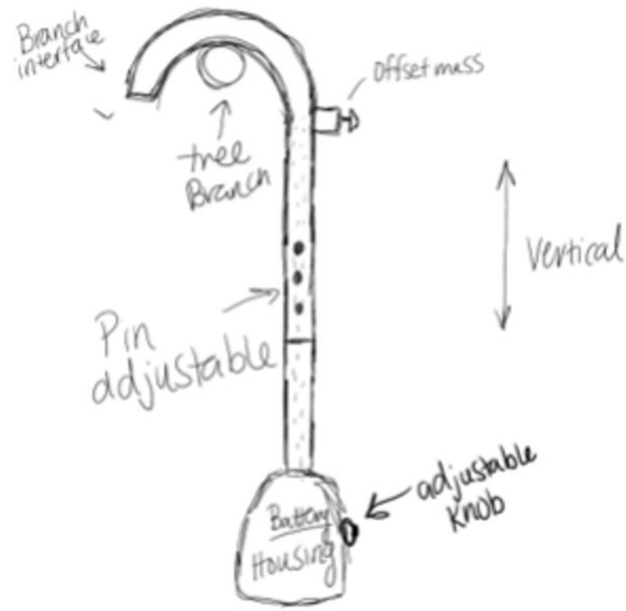


Figure 36: Hanging Circular Hook – Offset Mass Placement

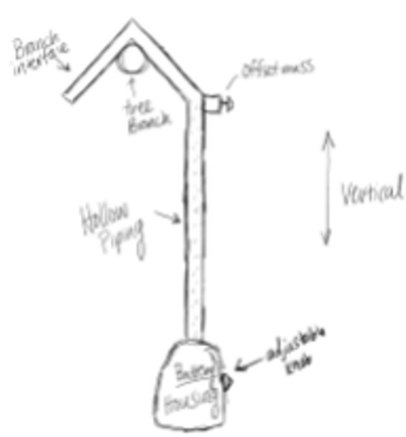


Figure 37: Hanging Triangular Hook – Adjustable Knob

3.4.3 Collection

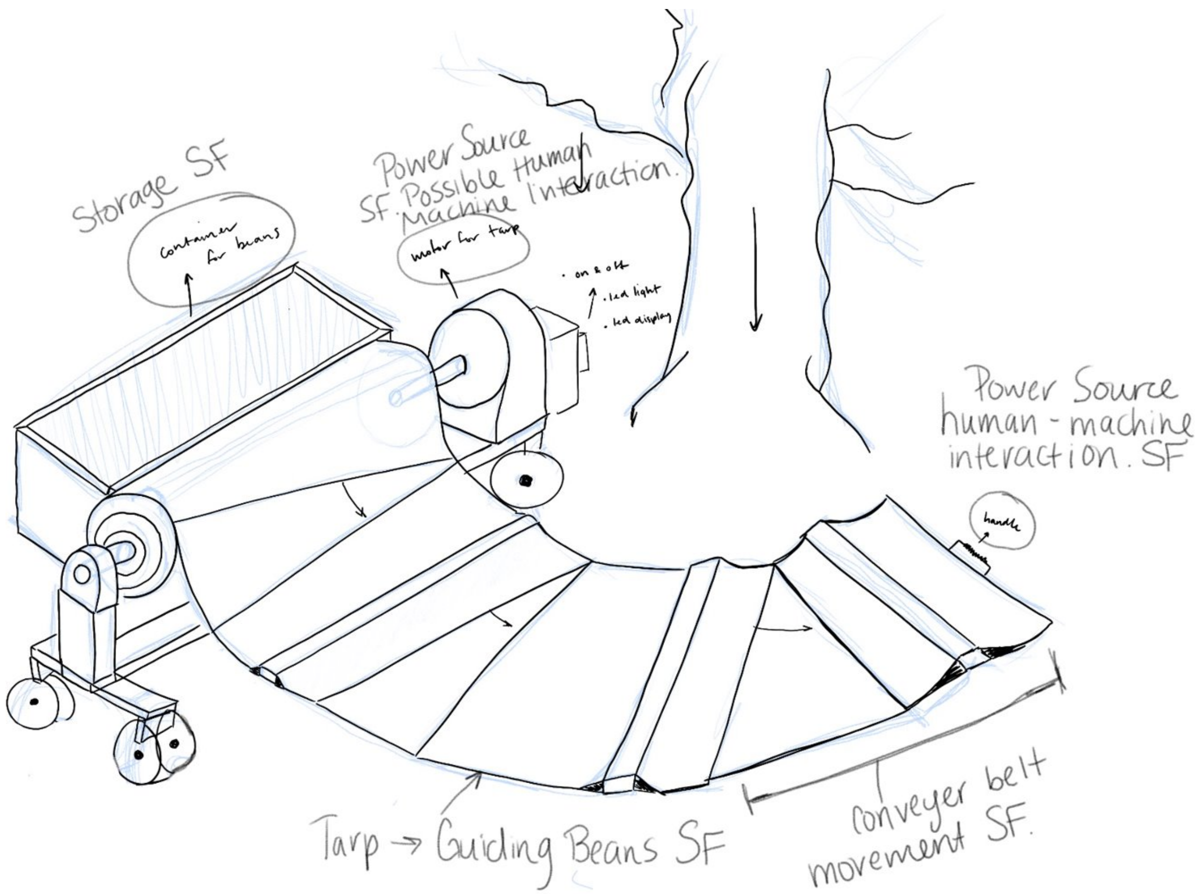


Figure 38: Retractable Conveyer Belt

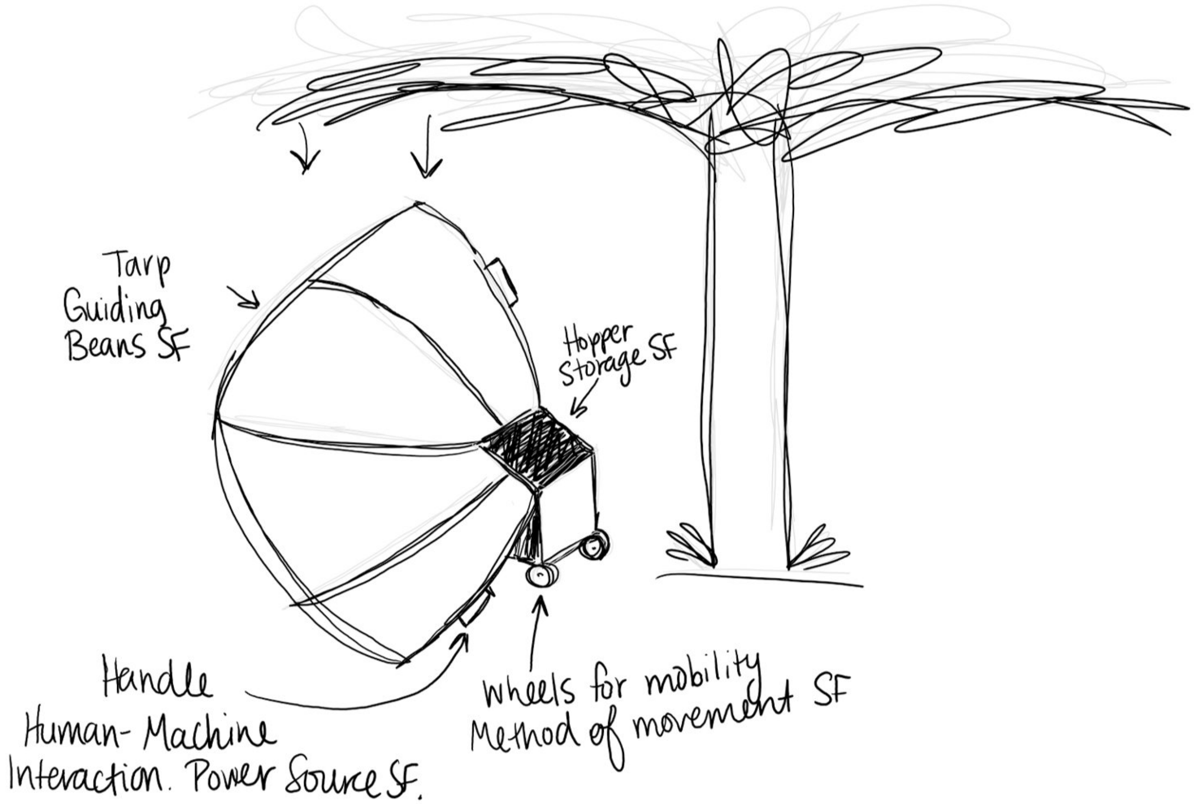


Figure 39: Half-Moon Portable Hopper

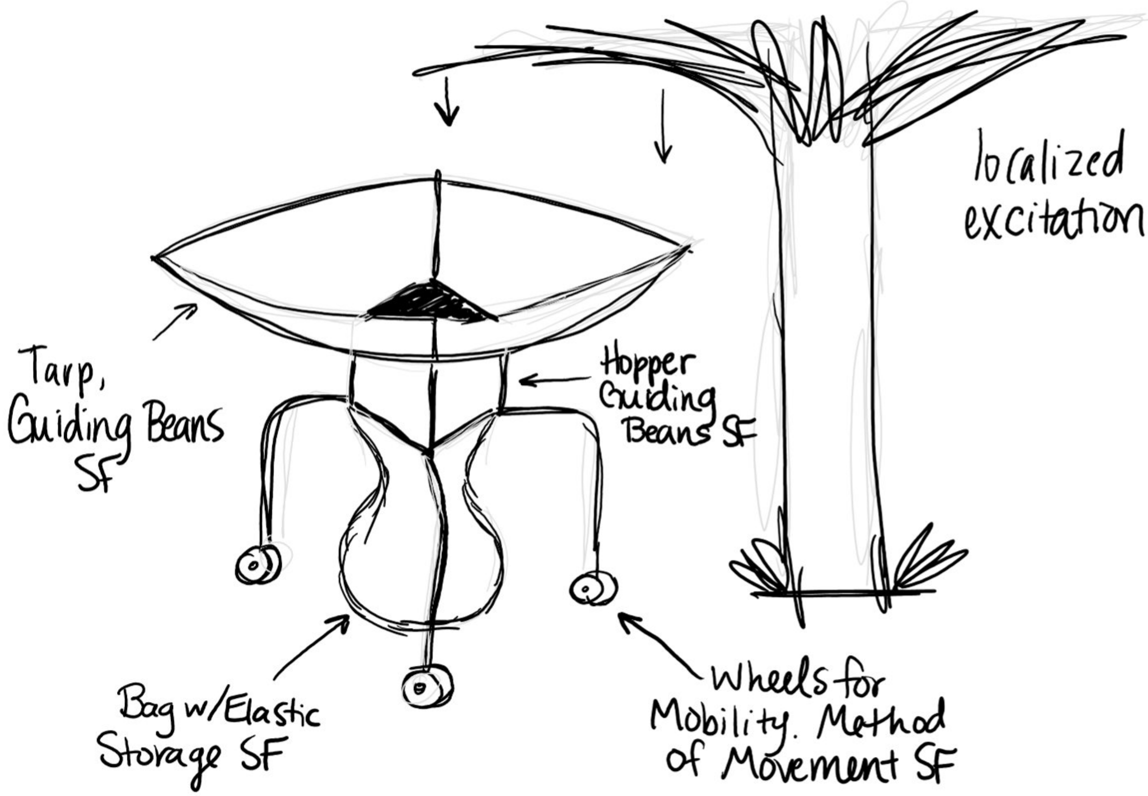


Figure 40: Portable Hopper with Fastening Storage

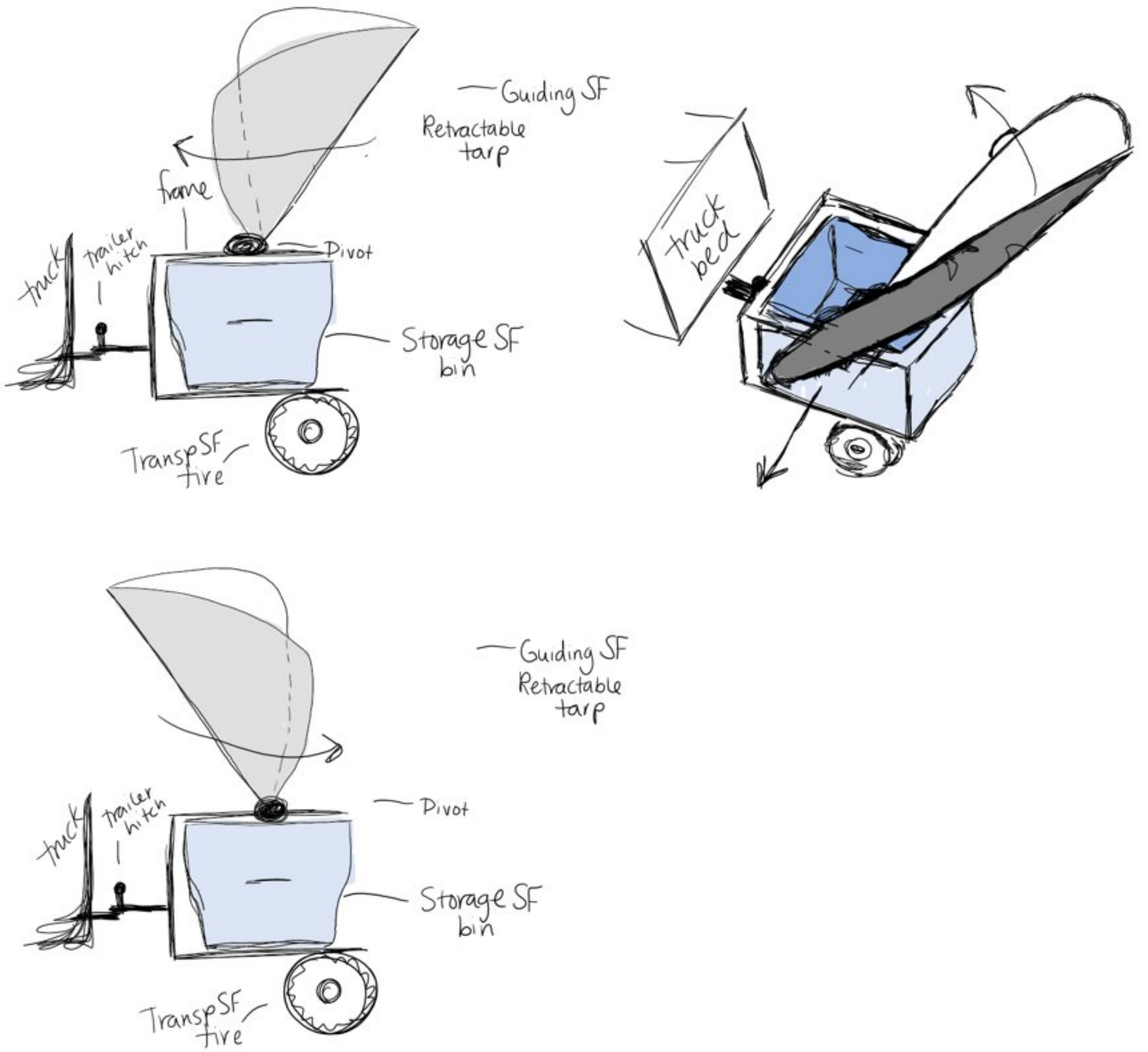


Figure 41: Pivoting Tarp Frame for Replaceable Bins

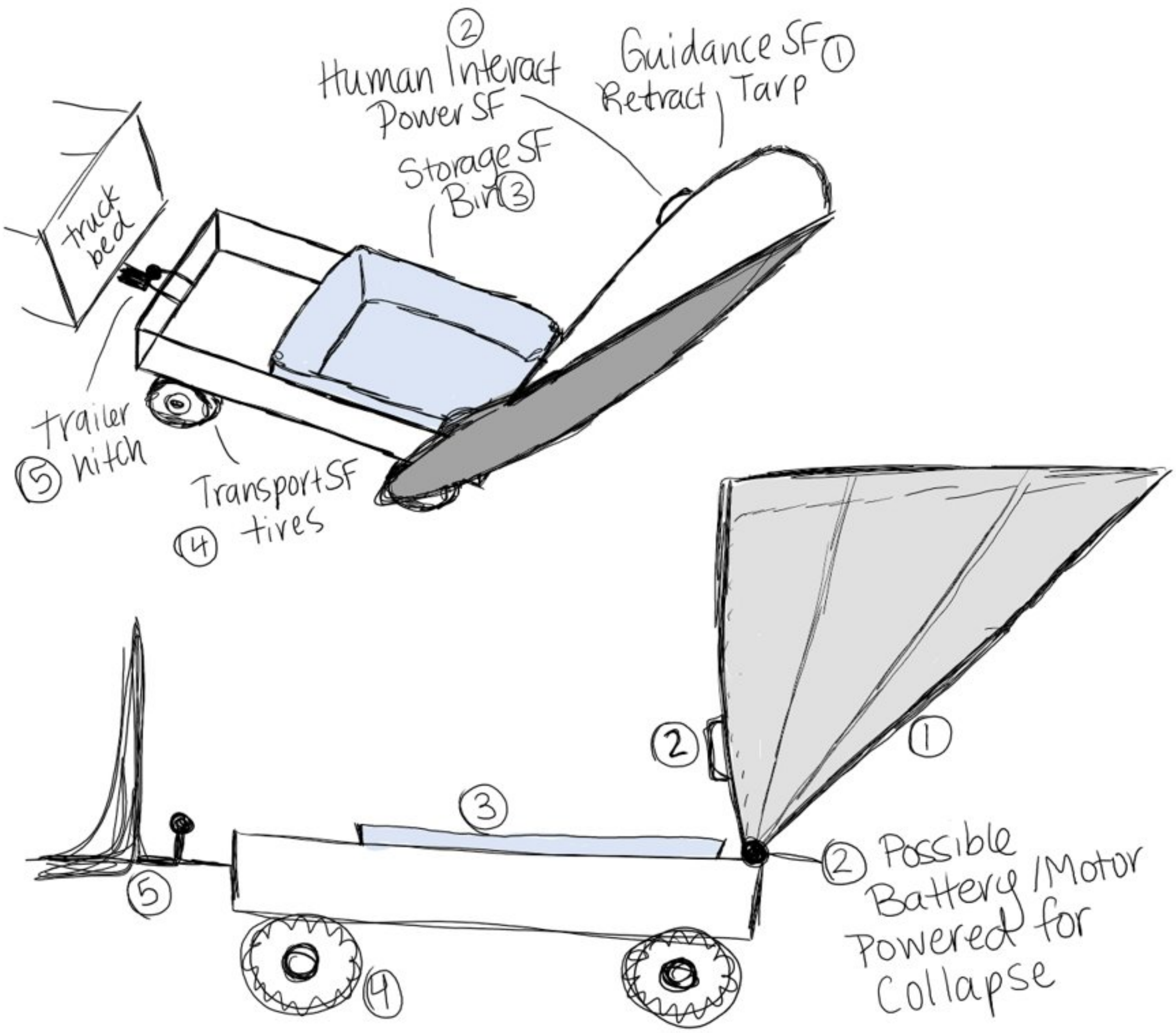


Figure 42: Retractable Trailer Tarp for Replaceable Bins

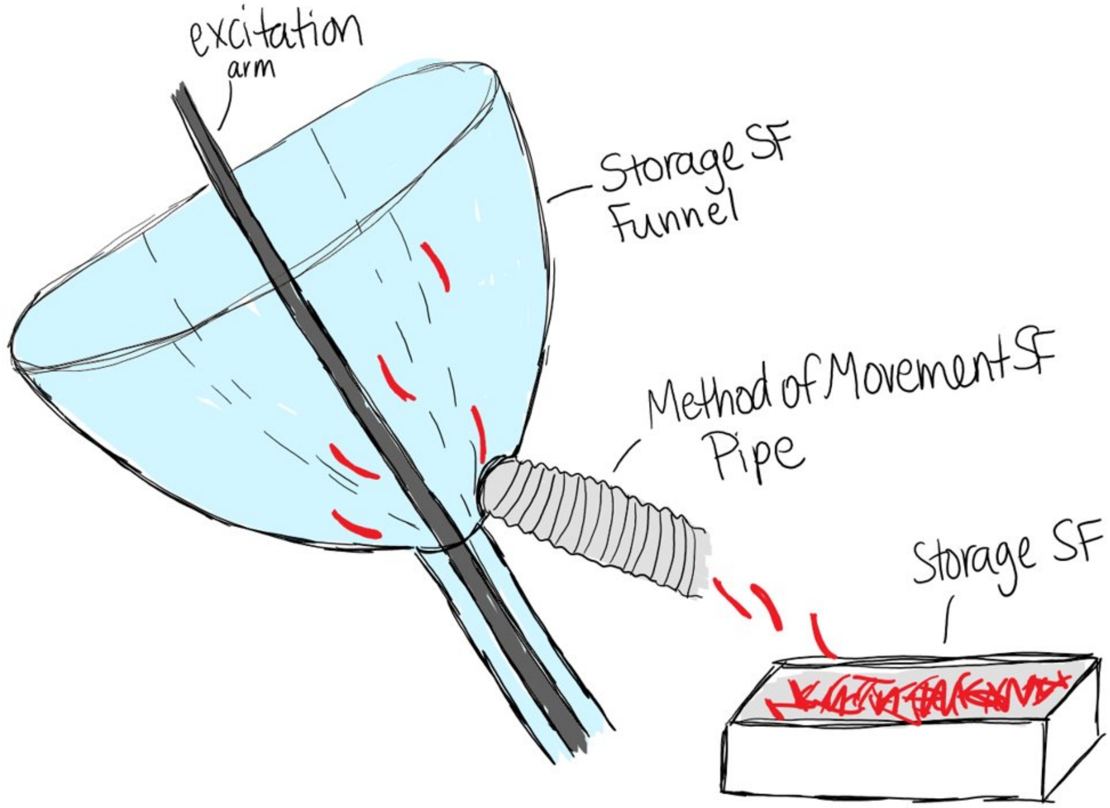


Figure 43: Integrated Funnel Collection System

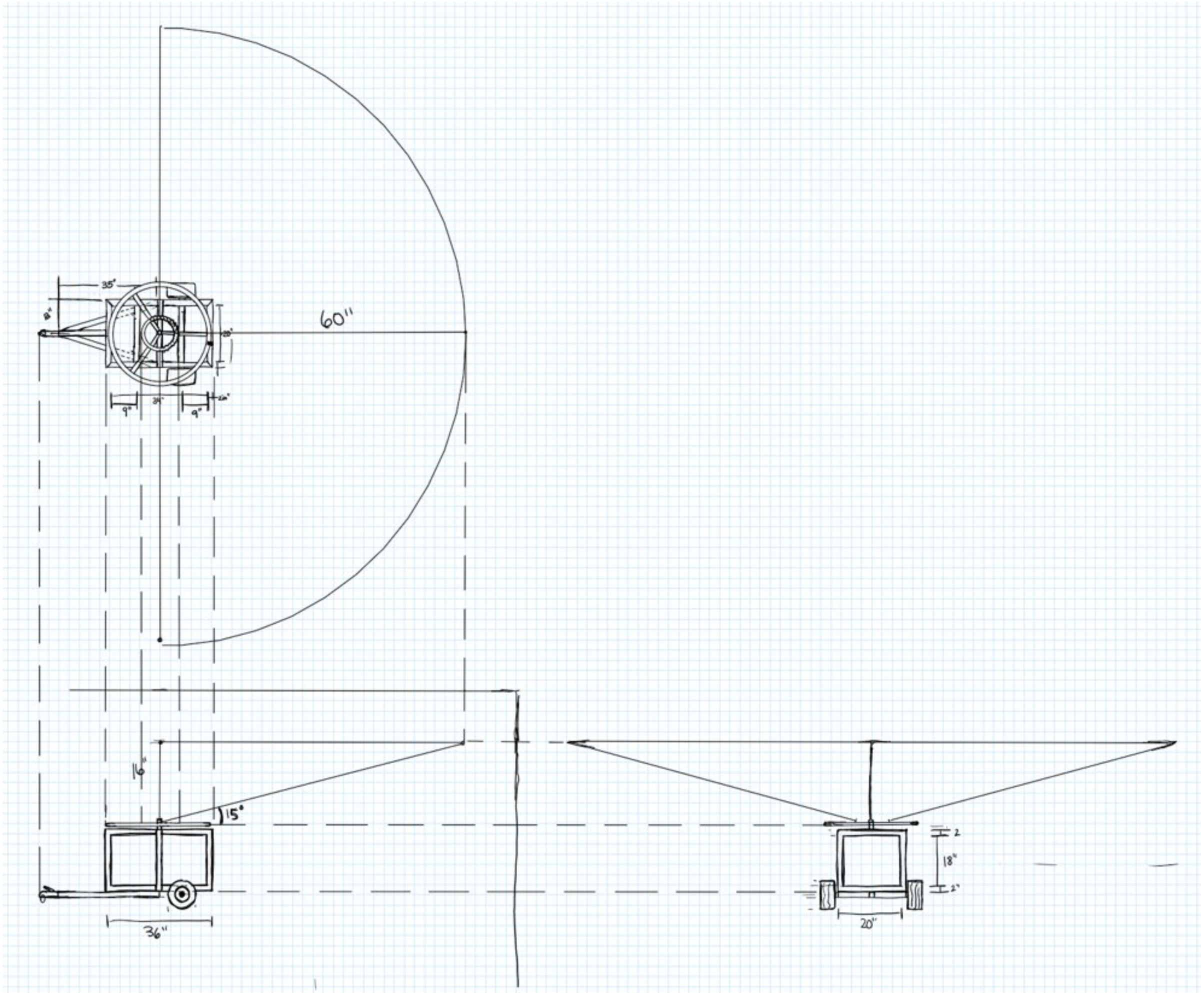


Figure 44: Pivoting, Adjustable Height 180 Tarp

3.5 Concept Variant Elimination

The concept variants that were created were subjected to an extensive elimination process that resulted in the survival of the final designs for each section of the project. Depending on the section of the project, the total concept variants were evaluated by a primary qualitative elimination and were reduced to three concept variants. Those three surviving concept variants were put through a secondary qualitative elimination process, such that the secondary qualitative elimination was quantity-based without numbers. Their numerical values were inferred through comparison between each other, such that they are ranked according to each criterion. From there, the surviving final concept variant is the final design for that part of the project.

3.5.1 Excitation

3.5.1.1 Primary Qualitative Elimination

For this elimination process, a datum was assigned to a specific design that is the neutral concept variant. The concept variants are evaluated by the following criteria: Ease of Use, Durability, Maneuverability, Cost, and Manufacturability. Ease of Use is worth three points, showing that it is the most important criterion. Durability and Maneuverability are worth two points, showing of their importance in the elimination process. Cost and Manufacturability will be considered as well, with both worth one point. The concepts are given a "+" if the concept variant has a better outcome than the datum, a "-" if the concept variant has a worse outcome than the datum, and an "S" if the concept variant has the same outcome as the datum. The "+" and "-" values are subtracted from each other for a total score. An overall negative or positive score shows the concept variant's comparison to the datum. The three concept variants with the highest scores will survive the Primary Qualitative Elimination and move towards the Secondary Qualitative Elimination process.

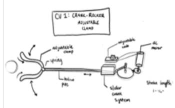
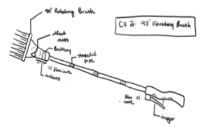
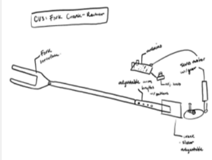
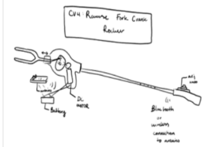
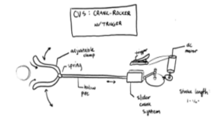
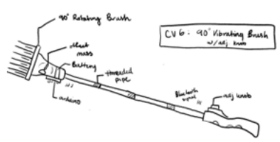
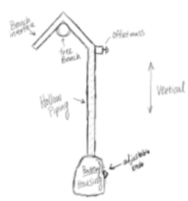
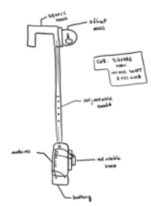
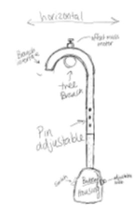
	Weight									
Ease of Use	3	S	S		-	S	S	+	+	+
Durability	2	-	-		S	-	-	+	+	+
Maneuverabilty	2	S	-		S	S	-	+	+	+
Cost	1	-	+	DATUM	S	-	+	+	+	+
Manufacturabilty	1	-	+		S	-	+	+	+	+
	+	0	2		0	0	2	9	9	9
	S	5	3		6	5	3	0	0	0
	-	4	4		3	4	4	0	0	0
	Total	-4	-2		-3	-4	-2	9	9	9
	Conclusion	The durability is compromised because of the spring design. The springs would not be able to cater to all branch sizes and frequencies (spring constant). The Manufacturability and cost are negatives because of the slider crank method. More parts will lead to increased weight, which makes is hard to handle.	The durabiloty is compromised because of the arm structure, threaded pipe parts leads to an increase in the amount of weak points, which could affect the stability and safety of the machine. The brush component cannot have a strong interface with the branches.	The slider crank method, the fork, and the arm makes this component the neutral/datum.	The motor is placed at the fork end of the component, rendering the machine to be top-heavy, affecting the ease of use.	The durability is compromised because of the spring design. The springs would not be able to cater to all branch sizes and frequencies (spring constant). The Manufacturability and cost are negatives because of the slider crank method. More parts will lead to increased weight, which makes is hard to handle.	The durabiloty is compromised because of the arm structure, threaded pipe parts leads to an increase in the amount of weak points, which could affect the stability and safety of the machine. The brush component cannot have a strong interface with the branches.	Design keeps the user from expending too much energy by not carrying it during the excitation process. The durability is increased because of the branch interface.	Design keeps the user from expending too much energy by not carrying it during the excitation process. The durability is increased because of the branch interface.	Design keeps the user from expending too much energy by not carrying it during the excitation process. The durability is increased because of the branch interface.

Table 17: Primary Qualitative Elimination for Excitation

The three concept variants that survived the Primary Elimination Process are the Hanging Triangular Hook – Adjustable Knob, Hanging Square Hook – Adjustable Knob, and Hanging Circular Hook – Offset Mass Placement.

3.5.1.2 Secondary Qualitative Elimination

The top three concept variants are evaluated by the following criteria: Method of Vibration, Arm Reach, and Surface Contact with Branch. Method of Vibration is worth three points, showing that it is the most important criterion. Arm Reach is worth two points, showing of its importance in the elimination process. Surface Contact with Branch will be considered as well, being worth one point. The numerical values of the concept variants were inferred through comparison between each other, such that they are ranked according to each criterion. Their rankings are multiplied by the number each criterion is worth. From there, those values are combined to a total score.

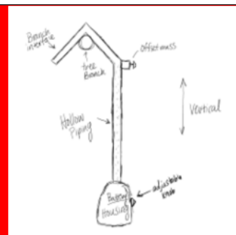
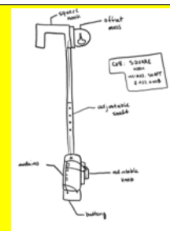
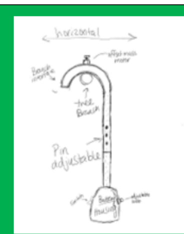
	Scoring			
Method of Vibration	3	1	1	3
Arm Reach	2	1	2	3
Surface Contact With Branch	1	2	1	3
Method of Vibration	3	3	3	9
Arm Reach	2	2	4	6
Surface Contact With Branch	1	2	1	3
	Total Score	7	8	18
	Conclusion	Motor on the side of the interface produces axial vibration rather than bending. The arm is unable to extend. The triangluar interface allows for increased surface contact with branches.	Motor on the side of the interface produces axial vibration rather than bending. The arm is able to extend, or can be modified to a telecoping pole. The square interface does not maximize the surface contact with branches.	Motor on top of the interface allows for bending vibration. The arm is able to extend, or can be modified to a telecoping pole. The circular interface maximizes the surface contact with branches.

Table 18: Secondary Qualitative Elimination for Excitation

The concept variant with the lowest score was the triangular, non-extending hook. Its minimal arm reach and its method of vibration is not desired. The square, extending hook does not maximize surface contact with the tree branch. The highest scoring concept variant is the circular, extending hook. This concept variant maximizes surface contact with the branch, maximizes arm reach, and will produce the bending vibration of the mesquite beans.

3.5.2 Collection

3.5.2.1 Preliminary Qualitative Elimination

For this elimination process, a datum was assigned to a specific design that is the neutral concept variant. The concept variants are evaluated by the following criteria: Durability, Mobility of

Guidance, Maneuverability, Cost, and Manufacturability. Durability is worth three points, showing that it is the most important criterion. Mobility of Guidance and Maneuverability are worth two points, showing of their importance in the elimination process. Cost and Manufacturability will be considered as well, with both worth one point. The concepts are given a "+" if the concept variant has a better outcome than the datum, a "-" if the concept variant has a worse outcome than the datum, and an "S" if the concept variant has the same outcome as the datum. The "+" and "-" values are subtracted from each other for a total score. An overall negative or positive score shows the concept variant's comparison to the datum. The three concept variants with the highest scores will survive the Primary Qualitative Elimination and move towards the Secondary Qualitative Elimination process.

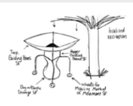
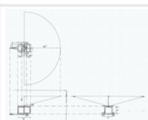
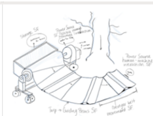
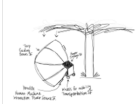
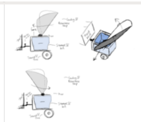
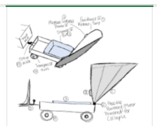
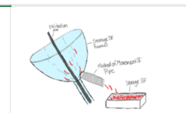
Round 1	Weight							
Durability	3	S	+	+	DATUM	+	+	-
Mobility of Guidance	2	S	+	+		+	S	+
Maneuverability	2	S	+	-		+	+	+
Cost	1	-	-	-		-	-	+
Manufacturabilty	1	-	-	-		-	-	-
	+	0	7	5		7	5	5
	S	7	0	0		0	2	0
	-	2	2	4		2	2	4
	Total	-2	5	1		5	3	1
	Conclusion	Increased cost and manufacturability without increases in durability, mobility of guidance, and maneuverability. Shape and design would be unsuitable for ranch terrain. Repeated replacement of bag with possible tearing.	Able to be transported easily because of the trailer hitch. Increased range of motion. High mobility, Strong tires can be used. Manufacturing Complexity is higher. Can attach to end of vehicle.	Minimal maneuverability, high cost, and complex manufacturability. The durability is higher with mobility of guidance, but the tarp would be exposed to touching the ground of the ranch. The design is unsuitable for ranch terrain.		Design is doable, a little more complex than Solution 2. Pivoting increases mobility of system and can be moved while the beans are being excited. However, the means of pivoting is not clear.	Simple design. Little mobility of guidance. The tarp woud be unable to rotate, limiting range of motion.	Durability is decreased because it is top heavy, could fail because of weight. The design allows more mobility and maneuverability but the manufacturability is way too high.

Table 19: Primary Qualitative Elimination for Collection

The three concept variants that survived the Primary Elimination Process are the Pivoting Tarp Frame for Replaceable Bins, Retractable Trailer Tarp for Replaceable Bins, and Pivoting, Adjustable Height 180 Tarp.

3.5.2.2 Secondary Qualitative Elimination

The top three concept variants are evaluated by the following criteria: Tarp Clearance/Range of Motion, Storage Size, and Weight. Tarp Clearance/Range of Motion is worth three points, showing that it is the most important criterion. Storage Size is worth two points, showing of its importance in the elimination process. Weight will be considered as well, being worth one point. The numerical values of the concept variants were inferred through comparison between each other, such that they are ranked according to each criterion. Their rankings are multiplied by the number each criterion is worth. From there, those values are combined to a total score.

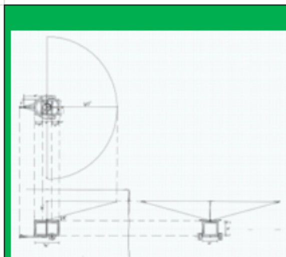
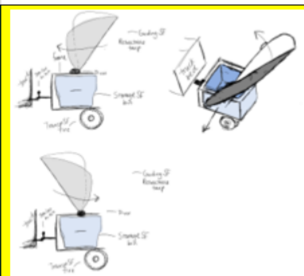
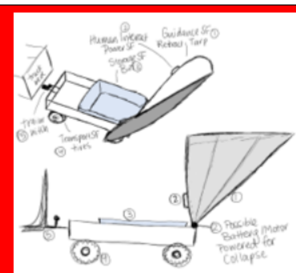
Round 2	Weight (Scoring 1-3)			
Tarp Clearance/Range of Motion	3	3	2	1
Storage Size	2	2	2	3
Weight	1	1	3	2
Tarp Clearance/Range of Motion	3	9	6	3
Storage Size	2	4	4	6
Weight	1	1	3	2
	Total Score	14	13	11
	Conclusion	Clearer means of rotation of tarp. Tarp can be supported. Larger range of motion. More components result in larger weight. A larger weight renders a larger tarp clearance/range of motion because of the frame's ability to resist tipping. Storage size is not maximized, but can be easily replaced.	Tarp is able to pivot to maximize range of motion and clearance. However, the frame is not as heavy as the first solution to counterbalance the weight of the tarp. This could hinder the tarp clearance/range of motion. The storage size is exactly like the top solution. The pivoting method is unclear for the tarp.	The tarp's range of motion/clearance is not maximized, given that the tarp is stationary. However, the storage size can be increased or decreased. The weight of the concept would be realtively similar to the top two solutions, but would probably be much easier to manufacture.

Table 20: Secondary Qualitative Elimination for Collection

The concept variant with the lowest score was the Retractable Trailer Tarp for Replaceable Bins. Its minimal tarp clearance/range of motion is not desired. The Pivoting Tarp Frame for Replaceable Bins is a good design, but there is not clear way to implement the pivoting tarp. The highest scoring concept variant is the Pivoting, Adjustable Height 180 Tarp. This concept variant maximizes tarp clearance/range of motion, maximizes storage size, and will be heavy enough to avoid tipping with the weight of the tarp.

3.6 Final Concept(s)

3.6.1 Excitation

The surviving excitation concept variant is the Hanging Circular Hook – Offset Mass Placement. This one was chosen after going through the elimination process due to the following main components. The circular hook was the best choice because it had the most contact interface between the hook and the tree branch. The motor placement was best suited for transferring the vibrational energy from the machine to the branch. And finally, the telescoping pole would be the safest option to reach the top of the tree and protect wires being run the length of the machine.

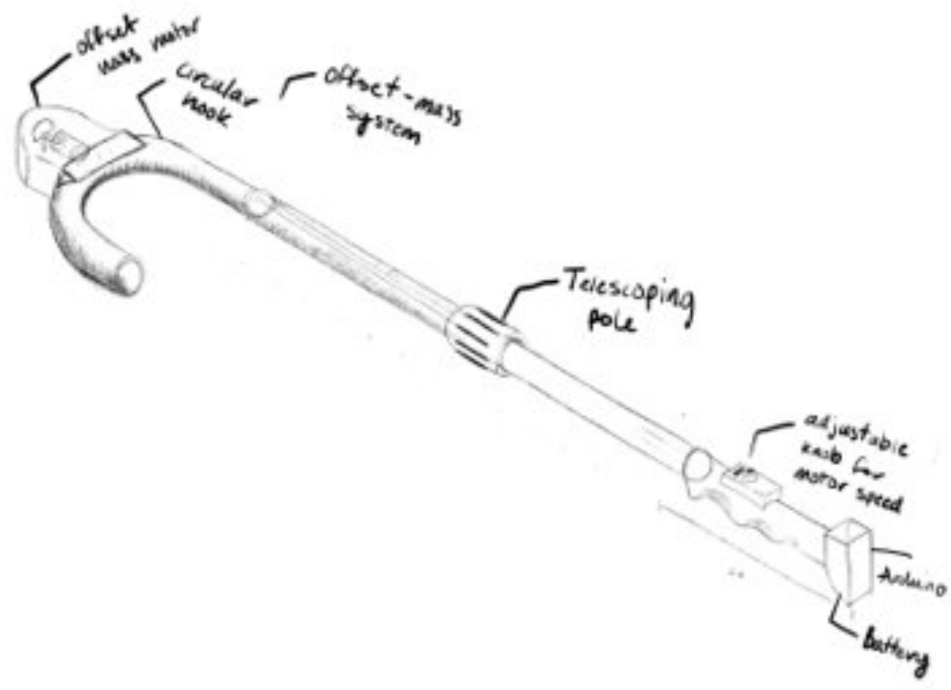


Figure 45: Circular Hook with Telescoping Pole (FINAL DESIGN – EXCITATION)

3.6.1.1 Parameters

Components of the excitation machine that are things we as a team know we want to implement into the design are as follows. The telescoping pole will be made of fiberglass due to its high durability and weight ratio. It will be 6-12 feet in length to maximize the reachability of higher branches. The motor that meets the perfect specifications for induce the correct level of vibration will be a Tiger Motors GetFPV MN4120-9 400kv. The hook material has yet to be determined, but it will have to be a material that translates the vibration across well and will have to be gentle enough against the branches of the tree. For the user's comfort an Ergonomic handle and grip will be implemented. To control the motor chosen and to induce a pulse width modulation, an Arduino will be programmed and implemented into the grip. Also connected to the Arduino for the user's convenience will be a LED screen for an RPM read-out along with a dial to control the level of RPM being transmitted to the excitation motor. The implementation of the excitation machine can be seen in the picture below.

Figure 46: Circular Hook with Telescoping Pole on Tree

3.6.2 Collection

The final surviving concept variant for collection is the Pivoting, Adjustable Height 180 Tarp as seen below. This variant was chosen because it has the best tarp clearance and range of motion due to the pivoting motion that the tarp would possess. The mobility is also important due to the rough terrain that this component would have to endure. The storage capacity is also important because if we did not choose a large enough storage space that constantly needed to be refilled then the process would gain another bottle neck and take even longer.

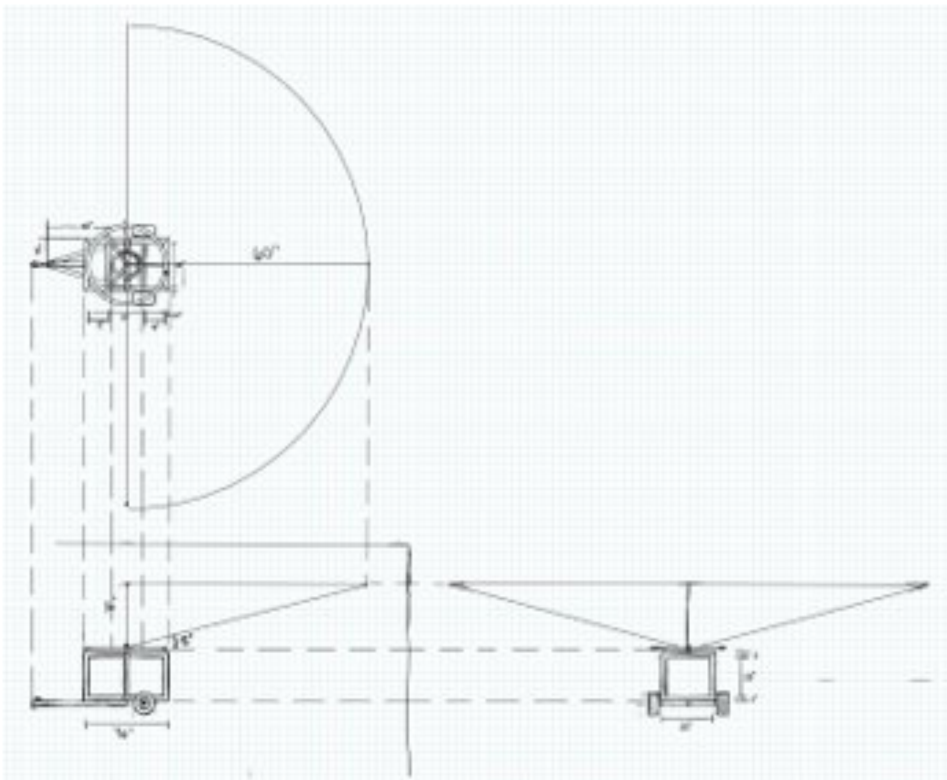


Figure 47: Pivoting 180 Degree, Adjustable Height (FINAL DESIGN – COLLECTION)

3.6.2.1 Parameters

Parameters that the team decided that are needed for the collection portion of this project are as follows. A steel frame will be constructed to encompass reusable bins that have the dimensions of 36” by 24” by 22”. The frame will have a 2” by 2” cross section. The wheels that will be attached to the sides have not been chosen to due to terrain of the ranch that the size will need to be confirmed by the ranch owners. The design includes a trailer hitch for increased mobility since the trees are very far apart at the ranch. The material of the tarp has yet to be determined due to the COVID-19 quarantine. Because of these circumstances the material testing needed to determine material toughness against the sharp points of the beans could not be done. Once the material is picked, however, the radius of the semicircular tarp will be 5 feet. There will be a range for the tarp angle due to the unique geometry of each mesquite tree. The branches can droop and hit the ground so there needs to be an angle that is 15^{o} or greater to be able to fit under the canopy.

3.7 Conclusion

In conclusion, with each elimination the team grew more confident in the choosing of the final concept variant. Each final concept has the best components from the Morphological chart that was then analyzed in the sub function chart. As each concept variant was made with each combination, the process of narrowing down the best one. Through our thorough elimination process the final concept variants survived and will now be explored further for prototyping to begin.

4 EMBODIMENT DESIGN

4.1 Introduction

The purpose of embodiment design is to direct the team to a certain point in the project by determining the necessary steps required to move forward with the project. The overall strategy that the team is to move forward with is the idea of prototyping and defining the proper parameters to re-create to move forward with testing and validation of the final product. The team is to determine key questions that are to be answered to ensure that the product meets the mark of a quality engineering project. Topics such as 3D printing, 3D modeling, prototyping, field testing, and analysis will be discussed in embodiment design to ensure this success.

4.2 Layout 1

To begin, the team needs to determine the expectations that must be placed to ensure that we conclude Senior Design I with the right footing to continue work over the summer and fall semesters. Some of the questions that were determined by the team were as follows:

- How are the stresses being estimated?
- What is the estimated maximum weight that can be carried by the user?
- How can the design be backed up by analysis?
- Will the weight of the design affect the user negatively?
- How practical is the design? Does it require a large amount of training to use?

The team discussed that in order to answer these questions, early prototyping must be done to expedite towards testing and to ensure a complete proof of concept of the final design for the future.

The collection prototype frame was created to physically determine the feasibility of design without expending the resources distributed by the university. Following the blueprint that was created on paper, the frame is completed. The frame is pictured below.

Figure 48: Collection Prototype

The main purpose of this prototype to understand the idiosyncrasies behind the tarp design, mobility, and the frame development. A main concern of the collection device is to understand the mobility of the whole frame. The clearance of the bottom of the frame and the top is what will ultimately determine the wheel sizes and selection for the frame. Were the frame too low, the frame will be damaged when it comes to contact with the rough ranch terrain.

For excitation, a rough CAD model of the final design was created to conceptualize the 3D physicality of the machine. The CAD model contains parts and designs for the components that were required for the final design. The excitation machine is pictured below:

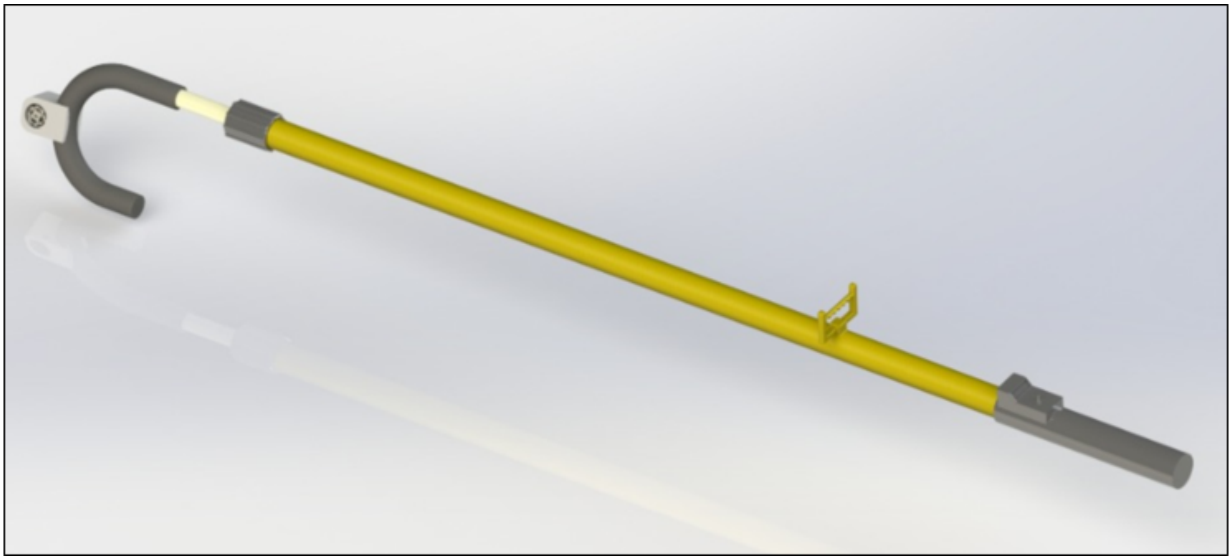


Figure 49: Excitation Prototype

The model contains the hook, motor, telescoping pole, handles, and dial for RPM Control. This rough CAD model is a baseline for future developments for the final product. The goal of the embodiment stage of Layout 1 is to refine this model. There is still new research to be conducted such as that of the offset-mass motor. The idea of completing this rough CAD model is to take the next step towards a final design. When complete, the final design can then be analyzed for weight analysis for deflections and to ensure that the user will be able to carry the final product.

Additionally, the team requires to develop a method of testing using 3D printing techniques. The testing will be used in lieu of using an actual mesquite tree branch due to the early bloom of the mesquite beans in the early summer months. 3D scanning of the beans is being investigated by the team to create an accurate 3D model for physical analysis. The 3D scans are pictured below:

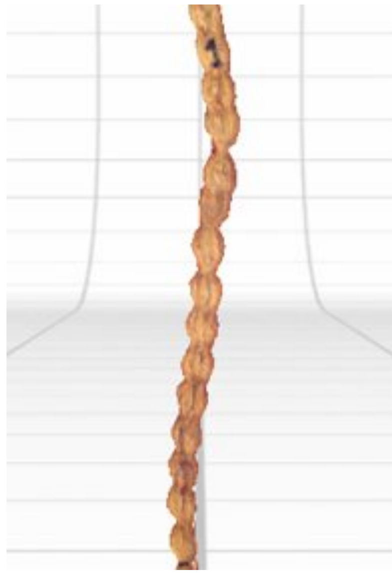


Figure 50: 3D Scan of Mesquite Bean 1

The main issue that is coming with 3D Scanning is that the scans themselves are inaccurate or missing vertices in the final scan when the beans have high amounts of curvature. The errors in scanning is pictured below.

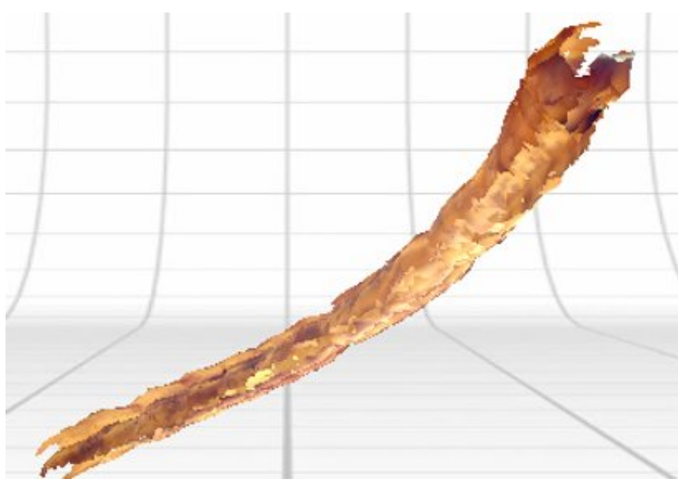


Figure 51: 3D Scan of Mesquite Bean Disconnected

Due to the crude design of the 3D scan, it is not able to produce an accurate 3D model to allow for printing. More research must be conducted over the course of the summer to ensure that a method of testing is possible.

Much of the work is complete by the end of Senior Design I. Future developments will be discussed in the next section to further define the required goals to answer the embodiment questions.

5 FUTURE WORK

5.1 Summer Plan

Determining the summer plan for the senior design project is of essential importance. The continuation of the project alleviates the pressures of the fall and allows for the movement of the project. Over the course of the summer, the goal that the project is to overtake is to continue to make concrete progress in embodiment design. A main priority is to layer the final design to have as many refinements to allow for an increased complexity of the final product. With this design completed, the manufacturing of parts and major assembly can then be conducted. The team is expected to complete a testing method by creating a mesquite branch and bean with a 3D printer and simulate bean drops and utilize the data collected to validate the analysis collected previously. Not only that, testing will highlight the flaws of the design and allow for a growth in design confidence.

5.2 Fall Plan

The plan for the fall is to continue with the theme of validation of the solution at hand. The prototypes are expected to be completed by this point in time. Validation of the analysis will be complete during this time in the semester with the main goal in mind that the final design will be in its most functional point in time. With the data collected and the machines changed to the proper parameters required to be successful, the project can officially conclude by December time.

6 BACK MATTER

6.1 Contributions

This project consisted of a vibrational analysis that was collected to understand what mode of vibration is best for the purpose of harvesting mesquite beans. This was a complete learning experience for the team. Exploring the mechanical properties of complex biological systems was very fulfilling, as was developing each of the CAD models of the differing mesquite bean geometries. The analysis of such systems allowed for concept variants to be created and explored. Concept variant eliminations allowed the team to generate two final designs for both excitation and collection by creating a systematic approach for ranking and eliminating concept variants. Doing so has allowed the team to gain experience in project management and in making logical and practical final decisions with proof of success.

6.2 Conclusions

Team 4-I has designed and developed ideas to facilitate the removal of the bottleneck within the mesquite bean industry and increase productivity. As a team, it was determined that localized excitation and collection would be the most efficient method of harvesting mesquite beans. This will reduce the loss of beans due to contamination and gain better control of specified excitation. The analysis of the mesquite beans natural frequency allowed the team to settle with a final concept variant with an adjustable frequency control and an offset motor. The final concept variant for collection was chosen based of storage size and tarp clearance. It had the largest tarp clearance along with the most efficient storage size while complementing the excitation system. The mesquite bean industry, in and of itself, can bring a positive, healthier aspect to Texas and to our home of the Rio Grande Valley. We, as a team, are proud of the work we have done, despite all the hardships that were endured because the COVID-19 outbreak. We are all ready to push forward to create a confident, safe, working product for mesquite bean harvesters.

6.3 Reflections

Project management is incredibly essential for any team. Without proper management or communication, none of the progress made this semester would be possible. It has been key to the success of this semester and working as a team to be flexible with our schedules and always remembering to approach every disagreement with humility and understanding. Every single day was a constant learning experience. Each of us developed lifelong attributes from leadership skills to learning how to adapt to a pandemic. As engineering students in a pandemic, we have learned the importance of research and self-teaching. We have practiced skills such as time management, self and peer motivation, and reaching out for help.

6.4 Acknowledgements

We would like to acknowledge the following individuals that have helped us in this journey:

- Dr. Arturo Fuentes
- Dr. Joanne Rampersad-Ammons
- Mr. John Pemelton
- Dr. Noe Vargas
- Mr. Gregory Potter
- Mr. Oscar Flores

Thank you for your time and patience as we navigated through this interesting semester. We appreciate all your feedback, and we are looking forward to impressing you with all that we can do!

7 REFERENCES

Bell, Willis Harvey and Edward Franklin Castetter. "The utilization of mesquite and screwbean by the aborigines in the American Southwest." University of New Mexico biological series, v. 5, no. 2, University of New Mexico bulletin, whole no. 314, Ethnobiological studies in the American Southwest, 5 5, 2 (1937). http://digitalrepository.unm.edu/unm_bulletin/29

Best Practices for Harvest & Processing of Mesquite. (2015, August 11). Retrieved May 10, 2020, from https://www.desertharvesters.org/harvesting-processing/

Bovey, R. W. (2016). Mesquite: history, growth, biology, uses and management. Texas: Texas A&M University Press. https://books.google.com/books?id=uRZDDQAAQBAJ&lpg=PA115&ots=lHbcJupNXq&dq=central%20america%20mesquite%20harvesting&pg=PA115#v=onepage&q=central%20america%20mesquite%20harvesting&f=false

GENDREAUX, S., Greg, & Morgan. (2019, May 29). Mesquite Bean Harvesting: Urban Farm. Retrieved May 10, 2020, from https://www.urbanfarm.org/2019/05/28/mesquite-harvesting/

Ferguson, Joseph M. LIMB SHAKER. 27 Aug. 1963.

Friday, Philip L, and Hartford Township van Buren County, Mich. FRUIT AND NUT HARVESTING APPARATUS. 26 May 1981.

Griffini, Alberto, and Giorgio Buoli. Tree Shaking Device for Collecting Fruits. 22 Jan. 2003.

Tyros, James C. OLIVE PECKER WITH SPEED CONTROL AND SELECTED PICKER DEMENSIONS. 16 Sept. 1986.

YOUNG, TERRY, et al. Mechanical Berry Harvester. 11 Sept. 2014.

Ediga Yathindra Goud, Dr. M. Nagaphani Sastry, K. Devaki Devi, Dr. H. Raghavendra Rao P.G. Student, Department of Mechanical Engineering, GPR Engineering College, Kurnool, AP, India Associate Professor of Mechanical Engineering, GPR Engineering Colle. " Mechanical Properties of Natural Composite Fibre Prosopis juliflora." International Journal of Innovative Research in Science, Engineering and Technology, vol. 5, no. 9, 2016, doi:10.15680/ijirset.

Castro-Garcia, et al. "Vibration Monitoring of the Mechanical Harvesting of Citrus to Improve Fruit Detachment Efficiency." *Sensors*, vol. 19, no. 8, 2019, p. 1760., doi:10.3390/s19081760.

d.o.o., DEWESoft. "Rotational and Torsional Vibration." *Dewesoft Training Portal*, training.dewesoft.com/online/course/rotational-and-torsional-vibration.

Liu, Ming, et al. “The Experimental Study on Apple Vibration Harvester in Tall-Spindle Orchard.” *IFAC-PapersOnLine*, vol. 51, no. 17, 2018, pp. 152–156., doi:10.1016/j.ifacol.2018.08.079.

Zhou, Jianfeng, et al. “Effect of Excitation Position of a Handheld Shaker on Fruit Removal Efficiency and Damage in Mechanical Harvesting of Sweet Cherry.” *Biosystems Engineering*, vol. 125, 2014, pp. 36–44., doi:10.1016/j.biosystemseng.2014.06.016.