DFD Hozhoni Foundation – Garden Device

Final Proposal

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Acknowledgements

The members of this Capstone team would like extend their greatest thanks to the community members of the Hozhoni Flagstaff Facility. Your insight was invaluable, your enthusiasm infectious, and this project would have been a far lesser success without your involvement. Thank you.

Executive Summary

For this project, the team was tasked to create a device which would allow several individuals living with their own unique physical disabilities to interact with a garden located in Hozhoni Facility in Flagstaff, AZ. The team decided to create a long-reach multitool device that could fasten to a user's wheelchair. Several prototypes were created, and countless in-field tests were done by members of the foundation. After completing a design of experiments and incorporating feedback from the users, the team opted to forego the wheelchair attachment in favor of a simple stand. The final device extended the user's reach and could be used as a trowel or rake with interchangeable tool heads. The design was a success, and members of the foundation were eager to have it brought to the facility at the project's conclusion.

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1 BACKGROUND

1.1 Introduction

The purpose of this project was to design, create, and implement a device usable by a person living with physical disabilities to complete tasks in a garden setting. These tasks may include watering, harvesting, trimming, and planting flora along with pulling weeds or moving pots. The team's primary objective was to create a device that effectively and reliably accomplishes at least one of these tasks. This device must be comfortable and safe to use without demanding much physical exertion from the user.

The team worked with the Hozhoni Foundation, a disability awareness group based in Flagstaff. Their facility houses several foundation members, most with physical disabilities, and on-site extracurricular activities including an art studio and a garden in which the device our team designs will be implemented. Our primary stakeholders were the Foundation itself and, more importantly, the individuals who will use our device.

Designing for disabilities requires engineers to design a product allowing persons with disabilities to accomplish a task they could not before. While this definition was true, it does not place enough emphasis on why such undertakings are important. If the purpose was simply to perform a task an able-bodied person could complete, then it would be done by an able-bodied person. Instead, a large motivator for designing for disabilities was the positive psychological effect on the users. People living with disabilities value self-sufficiency since it counteracts the feelings of helplessness or lack of control that may arise from their disability. Improving a person's mental health has a massive, positive impact on their life, and it was our duty as engineers to maintain and improve the wellbeing of our society through the application of science and mathematics. Doing so at an individual level was just as important. Our client recognizes this. The Hozhoni Foundation's mission statement is, among other things, " … to enhance quality of life, self-sufficiency, dignity and self-respect of the individuals we serve [1]." Our team aimed to do so.

1.2 Project Description

The project description provided to the team by the sponsor reads;

"The Hozhoni Foundation in Flagstaff, AZ has a large outdoor area for their clients with disabilities to enjoy during the day. Many areas of the gardens are wheelchair accessible. Many of the clients who have limited mobility desire the opportunity to interact more with the garden (water the corn field, rearrange potted flowers, etc.). Currently, there are no provisions that allow this in their gardens. This capstone team will develop and implement solutions that allow clients with disabilities opportunity to interaction with the gardens in new ways [2]."

Our team was comprised of self-motivated individuals with a similar interest; each member wishes to improve the quality of life of a person with disabilities. Due to this interest, the team met with the foundation several times over the year to discover what specific needs are unmet and what can be done to meet them.

1.3 Original System

This project involved the design of a completely new garden device. There was no original system when this project began.

2 REQUIREMENTS

The team's first actions were to create and approve a list of requirements complementary to the desires of the client. These requirements are separated into two groups: customer requirements and engineering requirements.

2.1 Customer Requirements (CRs)

After a thorough and detailed meeting with the client for this project, Mr. Justin Cartwright, a list of customer requirements was established to ensure the success of the project. According to Justin, the most important customer requirement was user safety. Any device used by the residents of the foundation must not carry the risk of accidental harm.

Low cost was the second important requirement. Designing and constructing the device should not exceed the provided $1500 budget, and overall construction costs should be kept low so the device could be easily reproduced.

Our client's third requirement was the device should be non-strenuous to use. This need also ties in with user comfort. Any device our team creates would most likely be used for long periods of time, since landscaping and garden upkeep can take up to several hours. An uncomfortable and exhausting device would not be beneficial.

The durability of the device plays a significant role in the value of this project. Working outdoors exposes our device to dirt, dust, weather, and consistent heavy loads. Our device must function in this environment for up to several years.

In addition to durability, the device should be usable by individuals with a variety of physical disabilities. The team's objective was to improve the self-sufficiency, and by extension the dignity and quality of life, of the members of the Hozhoni foundation. This objective will be most effectively met if our device can provide that luxury to as many individuals as possible.

These requirements, as well as the additional requirements generated during our benchmarking process and preliminary client meetings, are displayed on the House of Quality (HOQ) in Appendix A. Each requirement carries a relative weight, with 5 denoting highest importance and 1 denoting lowest importance.

2.2 Engineering Requirements (ERs)

After identifying the most important CRs and approving them with the client, the team brainstormed supplementary engineering requirements and the target value of each requirement. The final requirements were once again approved by the client and are listed in Table 1. These same requirements are used in the HOQ found in Appendix A.

Table 1: Engineering Requirements

Engineering requirement	Target	Rationale
Minimum edge thickness	= > 0.25 Inches	To allow for effective grabbing of larger objects
Design's weight	< = 25Ibs	To allow for ease of lifting and moving it around
Desired compression resistance	= > 100Ibs	To improve durability and ability to hold harder objects
Shear resistance for materials used	= > 50Ibs	To allow for durability and minimize wear and tear
Reach	5 feet	To maximize on the reaching out distance between the user and items
Design must accomplish multiple tasks	= > 2 tasks	To increase the importance of the design's use
Maximum noise	< = 60 decibels	To avoid disturbance while in use
Cost of manufacturing	< = $400	To allow for affordability and reduced maintenance costs
Power	< = 12V	To allow for increased operational power
Maximum dimensions for the design	2ft by 3	For effective storage
Least possible force	< = 5Ibs	To allow for ease of use
Battery life	= > 30mins	To allow for more use time
Assembly time	< = 5mins	To reduce complication and waste of time

2.3 Testing Procedures (TPs)

The team plans to conduct simple procedures to ensure the values for each engineering fall within tolerance.

2.3.1 Measuring Edge Thickness

The team will visually identify any and all edges under 1 inch on the device, then requisite a pair of metric calipers from the NAU D4P. Team member Michael Marner will contact the head of the program David Richter for permission.

2.3.2 Measuring Weight

The team will measure the weight of the device using an SAE floor scale. The device will be held in a makeshift bracket made of cardboard to ensure its entire weight was calculated. The weight of said bracket will be subtracted from the measured weight.

2.3.3 Measuring Tensile Strength

The team will limit testing to the main shaft of the device. Two floral pothooks will be attached to a cylindrical rod of the material of which the shaft will be made. One hook will be attached to a strong rafter so the rod was suspended, and bench press weights acquired from a third party will be added until yielding or failure occurs. The weight at which it occurs will be compared to the tolerance.

2.3.4 Measuring Shear Strength

The team will limit testing to the main shaft of the device. A cylindrical rod of the material of which the shaft will be made will be positioned between two raised surfaces and a metal clip attached to its center. Weight will be added to this clip until either yielding or failure occurs.

2.3.5 Measuring Reach

The team will measure the fully extended device with a 25 foot SAE tape measure already in our possession.

2.3.6 Counting Number of Tasks Device Can Accomplish

The team will bring the device to the garden environment in which it will be used and perform the tasks for which the device was designed.

2.3.7 Measuring Reflectivity

The purpose of minimizing reflectivity was to prevent eye pain from looking at the device when it was in direct sunlight. A team member will place the finished device in a patch of direct sunlight on a sunny day and stare at the device while keeping their eyes open for five seconds. If pain from brightness occurs, the team will lower the reflectivity and repeat as necessary.

2.3.8 Measuring Noise

Two team members will stand near each other and converse at a normal volume. A third team member will use the device to perform a task while standing parallel to the two conversing members, and a fourth member will stand equidistantly between the two parties. Typical human conversation ranges between 40 and 50 decibels, so the team surmises that if the sound of conversation overrides the sound of the device, the noise was within tolerance.

2.3.9 Cost of Manufacturing

After completing the device, the team will sum all expenses made in the process of construction and compare the total to the target value.

2.3.10 Minimize Power Usage

To determine the power output of any electric device, the team will use a voltmeter already in our possession on the positive and negative terminals and compare the measured value to the tolerance.

2.3.11 Measuring Dimensions in Use and in Storage

The team will use a 25 foot SAE tape measure already in our possession to measure the length, height, and width of the device. If the device was collapsible, it will be measured in both the fully extended and fully compacted positions. The product of these dimensions will give the volume of space occupied by the device, which will then be compared to the tolerances.

2.3.12 Minimize Force Input from User

The device will be suspended from a horizontal chin-up bar with a vise. The team will attach a five-pound weight to the input lever with a metal clip. If the device actuates, it was within tolerance.

2.3.13 Measuring Battery Life

If the device was electrically powered, the team will continuously actuate the device while clocking its runtime with a digital millisecond stopwatch already in our possession. If the device expends all power before thirty minutes have passed, the team will make changes and repeat until the device can run for thirty uninterrupted minutes.

2.3.14 Measuring Assembly Time

For the purposes of this project, assembly time refers to the time between removing the device from storage and the device being ready for use. The team will replicate this procedure and use a millisecond digital stopwatch already in our possession to record how long it takes. If the assembly takes less than five minutes, it was within tolerance.

2.4 Design Links (DLs)

DLs are components, features, or design choices which assure the final device meets each engineering requirement.

2.4.1 Foam Padding

Every surface of the device which will come in contact with the user will be machined smooth or covered with soft fabric or foam padding to ensure user comfort and safety.

2.4.2 Hollow Components

When possible, large and solid components of the final device will be hollow if the material permits. The absent material will lighten the device and lower manufacturing costs.

2.4.3 Metal Components

The final device will be used in an outdoor, garden setting and exposed to elements, grit, and general wear and tear on top of high-force use. To ensure structural integrity, the team aims to have the dominant structure of the device be constructed of metal.

2.4.4 Extended Handle

The portion of the device requiring user interface will be attached to one end of a long, slender pole. This will maximize the reach of the device while its slenderness will minimize its dimensions.

2.4.5 Multiple Tools

The final device will utilize numerous attachable and detachable tools. This will allow the device to accomplish numerous tasks.

2.4.6 Dark Coloring

The device will be used outside in the sunlight, meaning a low reflectivity was desirable. To ensure a low reflectivity value, the final device will be darkly colored and sheenless to avoid glare.

2.4.7 Easily Accessible Joints and Fasteners

Any joints between moving parts on the device will be accessible to ease assembly and so the user may apply lubricant to avoid wear and audible grinding or squeaking.

2.4.8 Elongated User Levers

Any levers on the device requiring user input will be elongated and provide handholds near its end. This will increase leverage and the torque, which in turn will minimize the force required from the user.

2.5 House of Quality (HoQ)

The team used a house of quality (HOQ) chart to organize all customer and engineering requirements, testing procedures, design links, and how each affects the other. The HOQ generated by the team over the course of this design project can be found in Appendix A.

3 EXISTING DESIGNS

After generating the CRs and ERs, the team researched existing devices capable of performing tasks in line with the requirements. After finding such devices, the team used benchmarking processes to start concept generation.

3.1 Design Research

Our team's first step was to meet with the client. Several team members visited the Hozhoni foundation to meet its residents and examine the on-site garden in which our design would be implemented. Team member Khaled Alanezi took several pictures of this garden. These pictures are shown in figures 1 through 6.

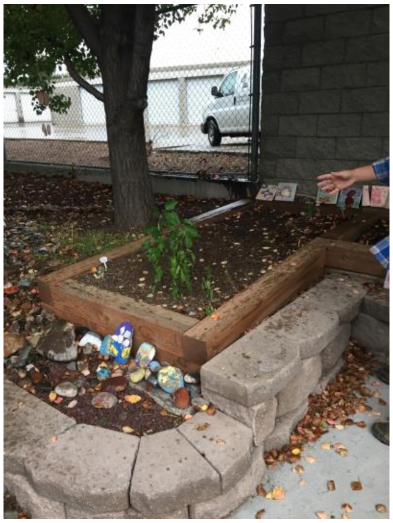

Figure 1: Hozhoni Garden Flower Box (1)

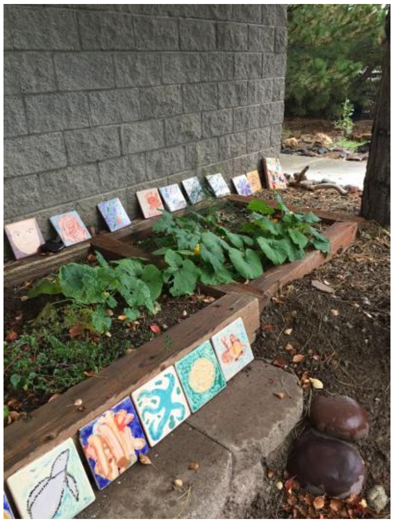

Figure 2: Hozhoni Garden Flower Box (2)

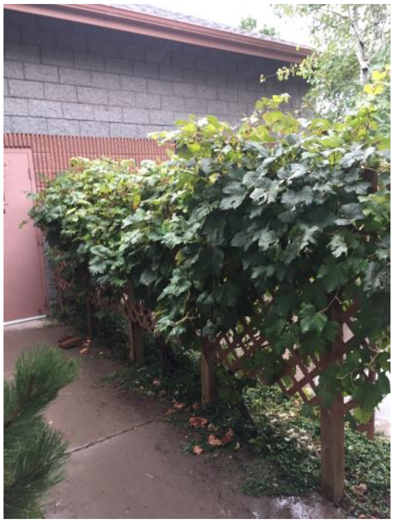

Figure 3: Hozhoni Garden Palisades

Figure 4: Hozhoni Garden Flower Box (3)

Figure 5: Hozhoni Garden Flower Box (4)

Figure 6: Hozhoni Garden Corn Field

During this meeting, our team also took time to discuss the CRs with our contact Justin Cartwright. We compared these requirements to those created during team brainstorming sessions to create the final list of CRs discussed in **2.1 Customer Requirements (CRs)**.

The team's next step was to benchmarking. To accomplish this, the team started researching different websites to find existing devices to get familiar with different concepts and ideas that are related to the project needed. The team researched existing gardening tools and devices that can be helpful for brainstorming new ideas that are realistic and fulfill the customer requirements approved from the costumer. One of the benchmarking techniques was comparing different existing devices and listing the pros and cons for each and how different devices can be upgraded and developed. Several team meetings narrowed the combined list into the devices discussed in section **3.2 System Level**. The team analyzed these devices and identified the most common subsystems, then decided which subsystems would best suit our CRs and construction limitations.

3.2 System Level

After benchmarking, the team compiled all the data and categorized it. The team realized our benchmarking data could be sorted by three system level descriptions.

3.2.1 Existing Design #1: Long Reach Garden Tools

A common element of the designs our team discovered was modifying existing tools that require standing up so they may be used while sitting down or vice versa. This was applicable since many residents of the Hozhoni foundation are wheelchair bound. Figures 7 and 8 display two such devices: an extended shovel and claw grabber.

Figure 7: Extended Shovel [3]

Figure 8: Claw Grabber [4]

3.2.2 Existing Design #2: Power Edge Trimmers

Similar to **3.1.1**, these devices allow a sitting person to perform a task usually limited to a standing person. However, these devices have the added benefit of making a task usually requiring both hands into one requiring only one hand. Applying this design would make our device more applicable to a wider array of individuals with different physical disabilities. Two trimmers, one requiring natural motion and one with ground support, are shown in figures 9 and 10.

Figure 9: Edge Trimmer [5]

Figure 10: Edge Trimmer (supported) [5]

3.2.3 Existing Design #3: Compacting Devices

The third most common system involved turning existing tools into smaller, more accessible versions of themselves. Implementing this type of design would most likely keep construction costs down since it would require less materials. An example of a compact dolly was shown in figure 11.

Figure 11: Compact Pot Dolly [5]

3.3 *Subsystem Level*

The devices listed in **3.2 System Level** accomplish their functions by implementing a variety of different mechanisms. Our team decided to analyze three subsystems: extending reach, converting two-handed use into one-handed use, and compacting existing devices.

3.3.1 Subsystem #1: Extending Reach

This includes devices allowing the user to physically reach objects where they otherwise could not. This was especially applicable to persons in wheelchairs since these devices allow them to accomplish tasks as if they were standing. Since this was the most mechanically complex of the three, a functional decomposition model has been provided in figure 12.

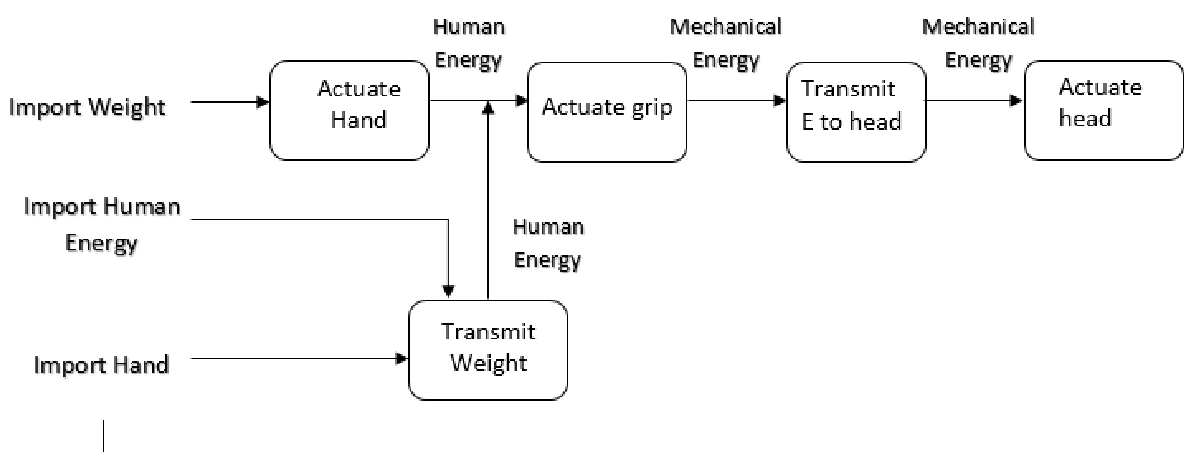

Figure 12: Extending Reach, Functional Decomposition Model

3.3.1.1 Existing Design #1: Elongated Handle

Refer to figures 7 and 8 for examples of elongated handles. These handles are typically long, solid, thin, and shear-resistant shafts.

3.3.1.2 Existing Design #2: Telescopic Handle

These rods are typically found on telescopes, as the name suggests, and can be compacted into a short annulus structure. This would be in accordance with our CR of compactability.

3.3.1.3 Existing Design #3: Hoses

Hoses are flexible, hollow tubes typically used to transport fluids over a distance. Their flexibility allows a user to 'hook' objects away from them.

3.3.2 Subsystem #2: Converting Two-Handed Use to One-Handed Use

Many persons with physical disabilities have difficulties using one or both of their arms. Creating a device with this system would expand our device's user base.

3.3.2.1 Existing Design #1: Hand and Elbow Grips

These devices provide handgrips and elbow contacts to transfer the load from a user's wrist to their forearm. The added strength makes operating traditionally two-handed tools possible. Refer to figure 7 for an example of this subsystem.

3.3.2.2 Existing Design #2: Ground Support

These designs add wheels or ground contact to devices that traditionally only use hand contact. The added support takes weight off of the user's arms and wrists, rendering several traditionally two-handed tools possible to use. Refer to the trimmer in figure 10 for an example of this design.

3.3.2.3 Existing Design #3: Removing Features

Removing features from existing devices limits its use, but may minimize its dimensions.

3.3.3 Subsystem #3: Compacting Devices

Modifying existing devices to be smaller saves manufacturing costs and opens the possibility of wheelchair-bound individuals using them if the device was designed to be easily accessed while sitting down.

3.3.3.1 Existing Design #1: Shortening

It stands to reason that most standing humans are taller than most sitting humans. In some cases shortening a device could make it more user-friendly to individuals who are almost constantly sitting in wheelchairs. Figure 11 was an example of shortening a traditionally tall dolly into dolly accessible while sitting down.

3.3.3.2 Existing Design #2: Adding Supports

Adding devices such as clips or straps instead of additional handholds saves space and allows accessibility for individuals with limited or no use in one hand. Figure 11 exemplifies this concept by adding a small clip near the top of the load.

3.3.3.3 Existing Design #3: Collapsible

Like the telescopic handle described in ***3.3.2.1***, making a device collapsible allows it to decrease its size.

4 DESIGNS CONSIDERED

Once the benchmarking was complete, the team began the process of concept generation. The team used two approaches to generate designs: the C-Sketch method and the gallery method. The C-Sketch process required each team member to create an original design in five minutes, then pass their design to the next member and receive the sketch from the previous member. After another five minutes of analysis and adding features to the sketches, the sketches are passed again and the process was repeated. The gallery method was much simpler. Each team member drafted three, detailed sketches individually, met as a team, and discussed each concept in detail. 20 designs were drafted in total. After discarding the designs that were unfeasible in an obvious way, the team was left with the 10 sketches shown in figures 13 to 22.

4.1 Design #1: Seed Dispenser

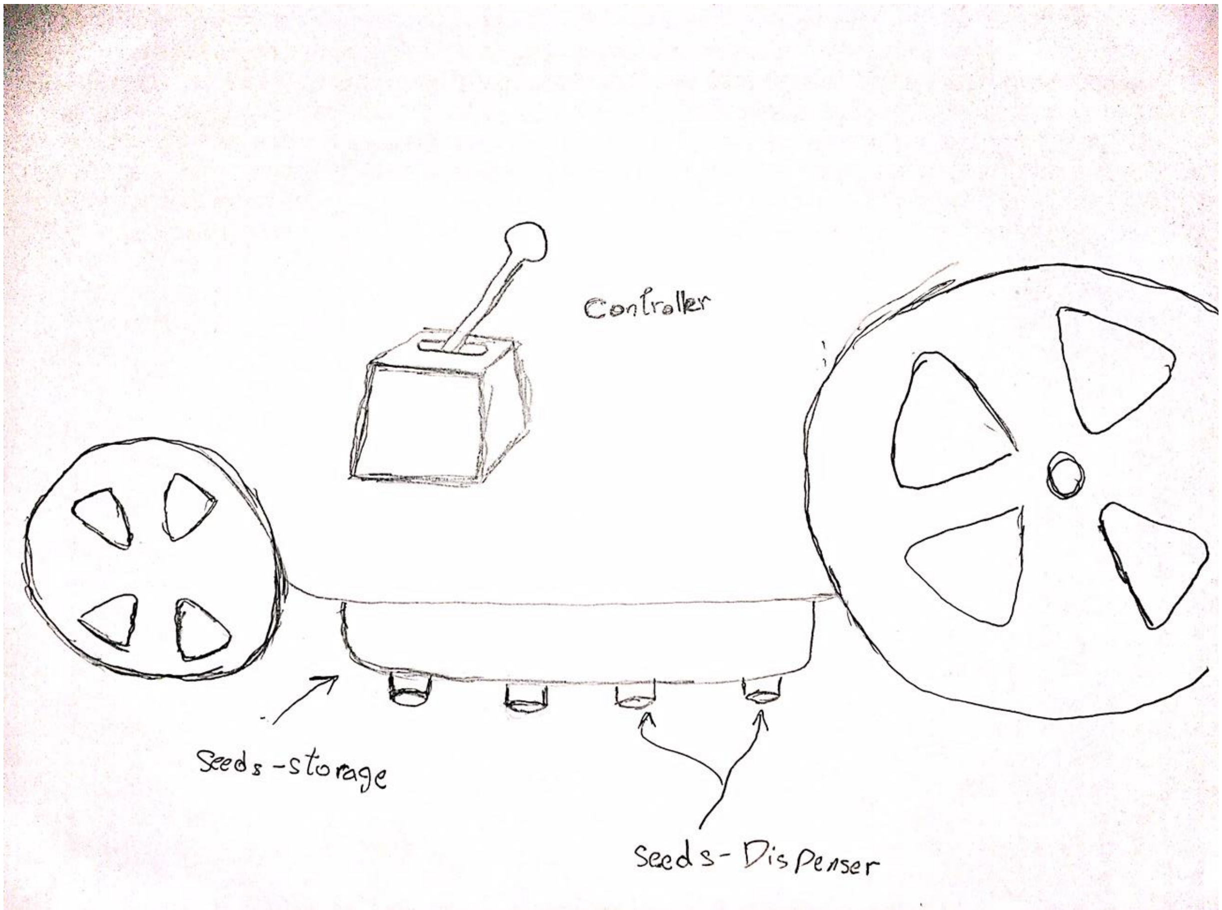

Figure 14: Seed Dispenser

This device will go under the wheel chair. It has a seed storage container to store different kind of seeds and a controller to control the exit of the seeds through holes. The benefits of this device are its portability and ease of use, but it only accomplishes one task.

4.2 Design #2: Sorting Board

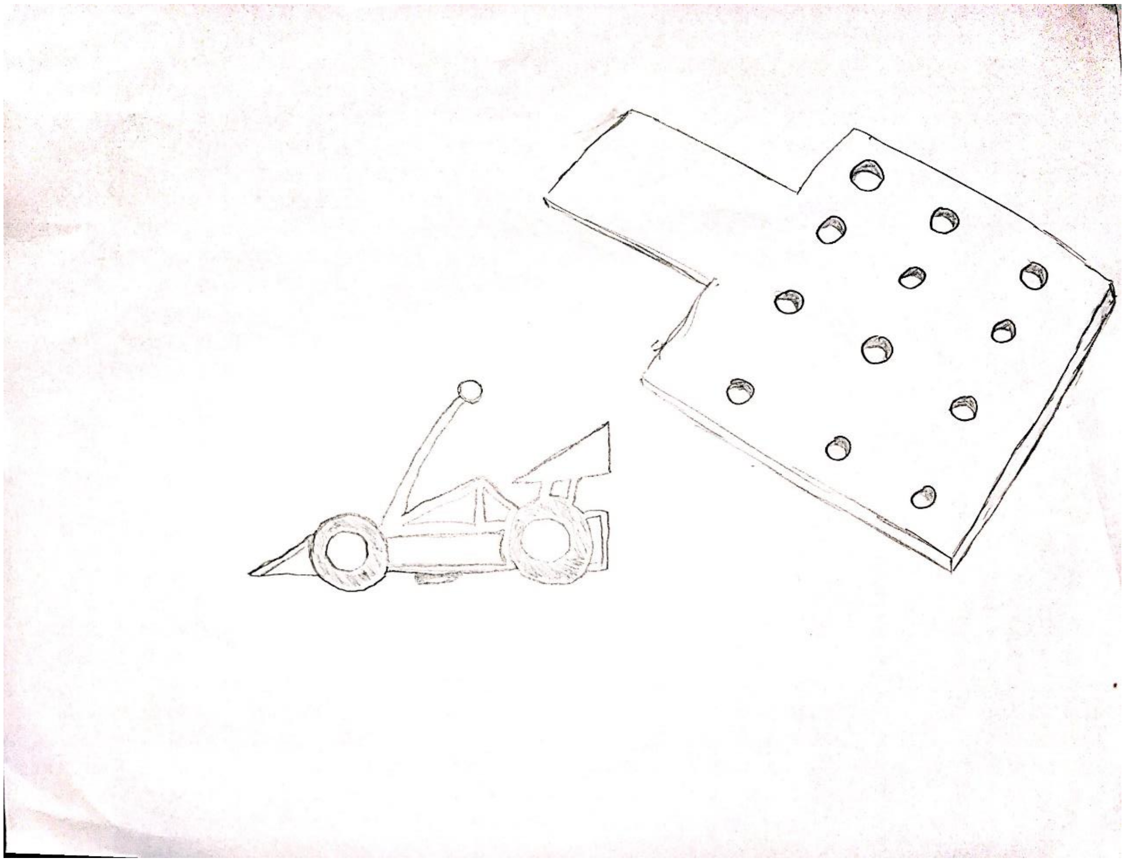

Figure 15: Sorting Board

The large board with remote controlled car, this design was a large board with some holes on top of it so the user can control the car to the holes he wants and he could trim or water the plants through the holes.

4.3 Design #3: Portable Watering Device

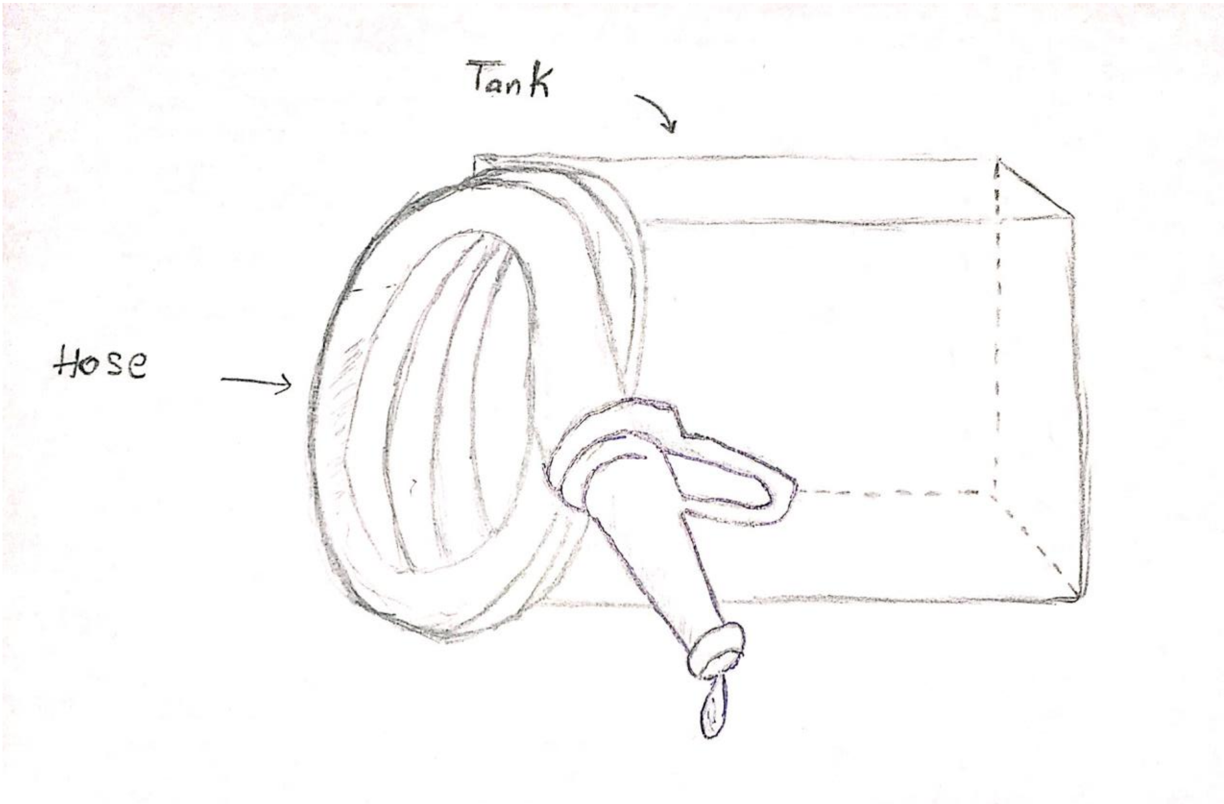

Figure 16: Portable Watering Device

A pressured water hose, this design was two parts design a hose and water tank that will be attached to the back of the wheel chair.

4.4 *Design #4: Auto Sprinkler*

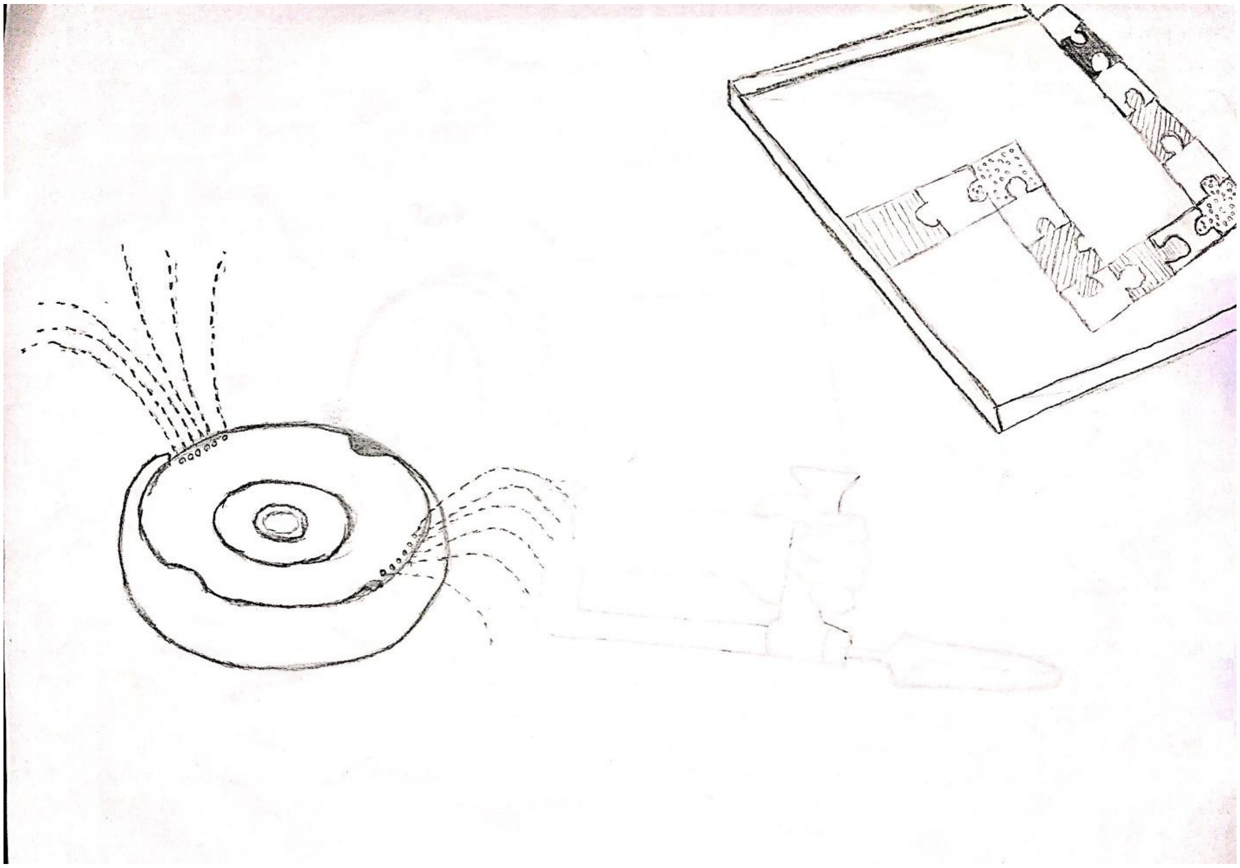

Figure 17: Auto Sprinkler

The remote-controlled watering device, this design was a bio inspired design which was like a whale and how the whale spray water. And about this design it could be a fun game to the user so he can place the large wooden puzzle on the area and organize it however he wants on the garden.

4.5 Design #5: Trimmer with Basket

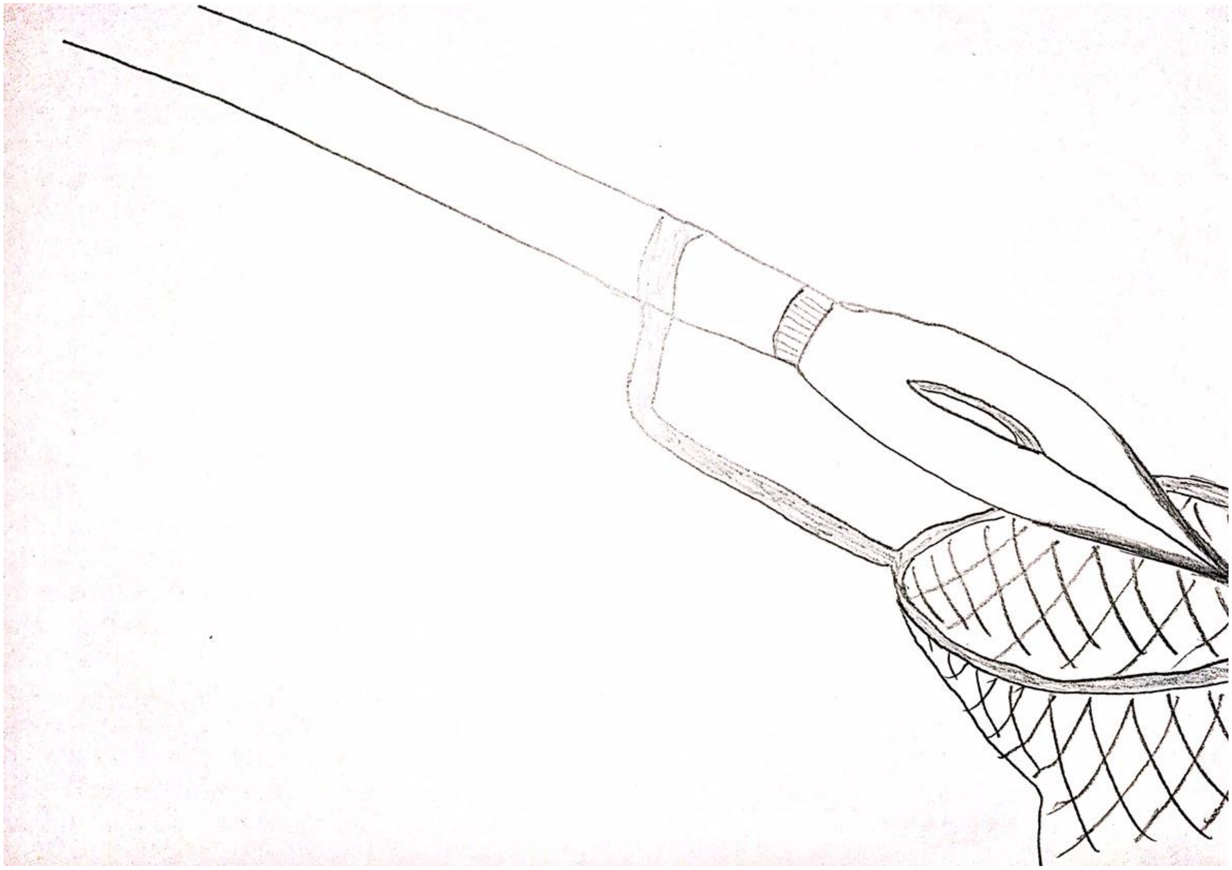

Figure 18: Trimmer with Basket

The cutter with a net, this design basically a cutter worked like a scissors and there was a net under it so if the under tried to cut something such as leaf or a fruit the object will fall inside the net.

4.6 *Design #6: Electronic Arm Tool*

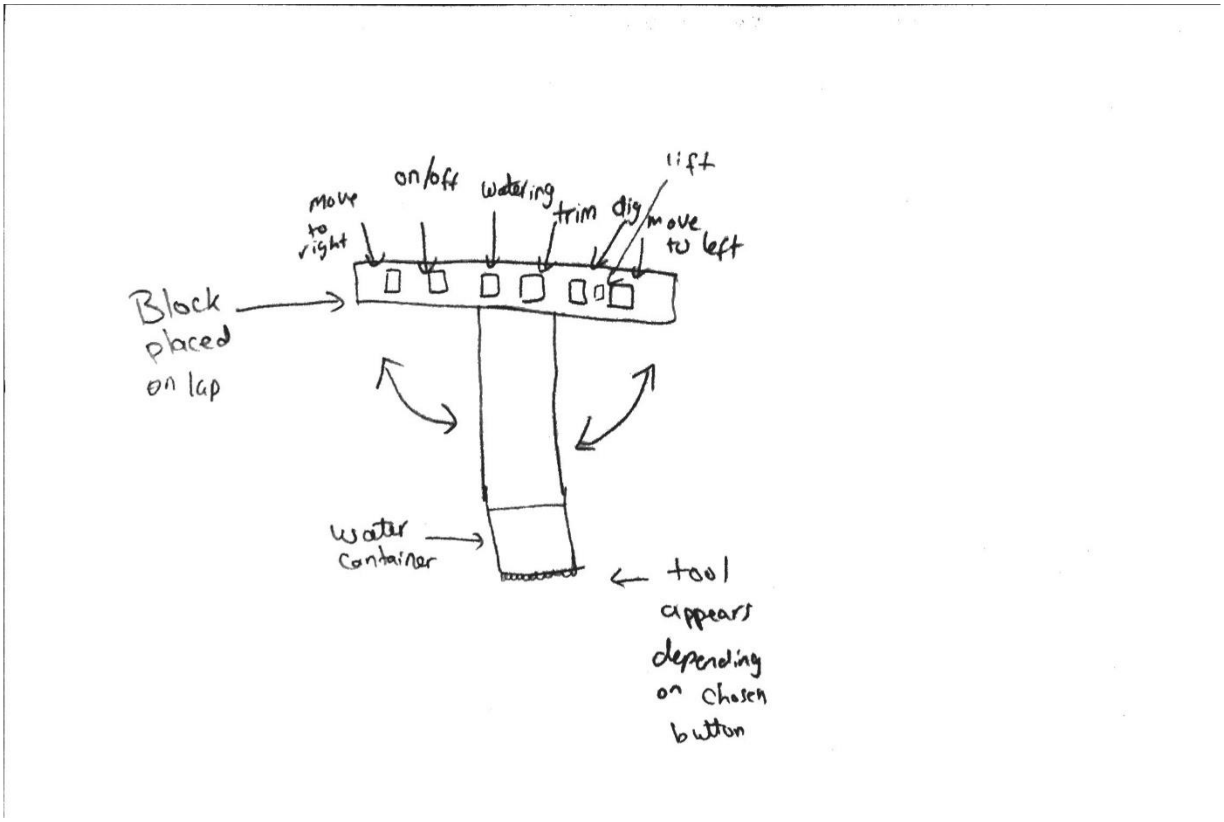

Figure 19: Electric Arm Tool

This design was made up of a board with ignition buttons that was placed on the lap of the user while he/she was sitting in a wheel chair. The board has a stretchable electric stick attached to it which has an open end for different tool to show depending on the ignition button chosen by the use. The device can do a lot of tasks including digging, cutting, trimming and watering.

4.7 Design #7: Fixed Rake

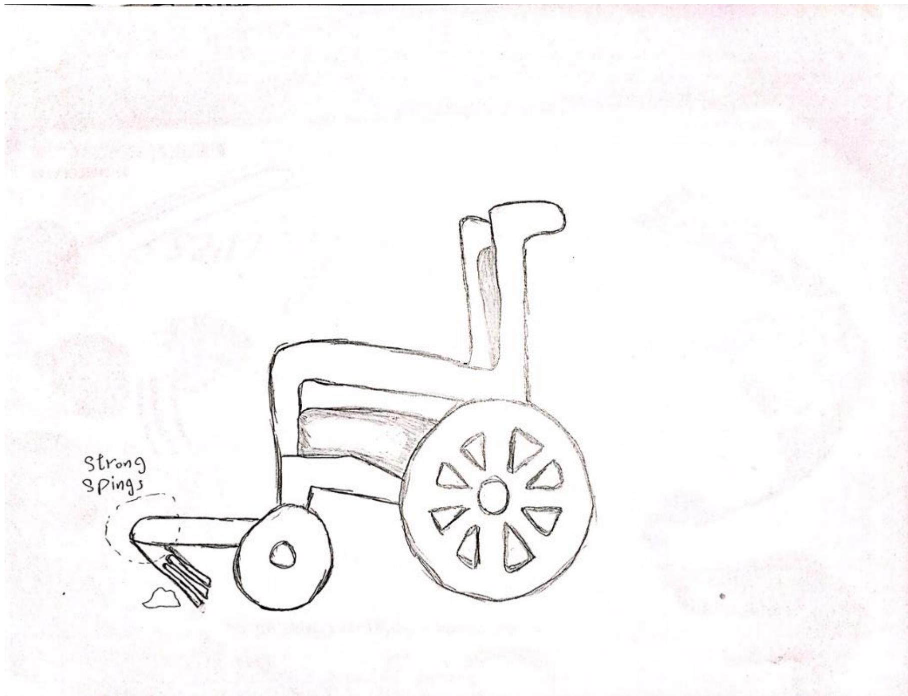

Figure 20: Fixed Rake

This design was a simple rake that was attached to a wheel chair with a huge back tire and wheel. This device was helpful for cleaning and wiping huge areas by simply moving the wheelchair by the user. It disadvantage was that it does not fulfill many tasks.

4.8 Design #8: Mechanical Arm Tool

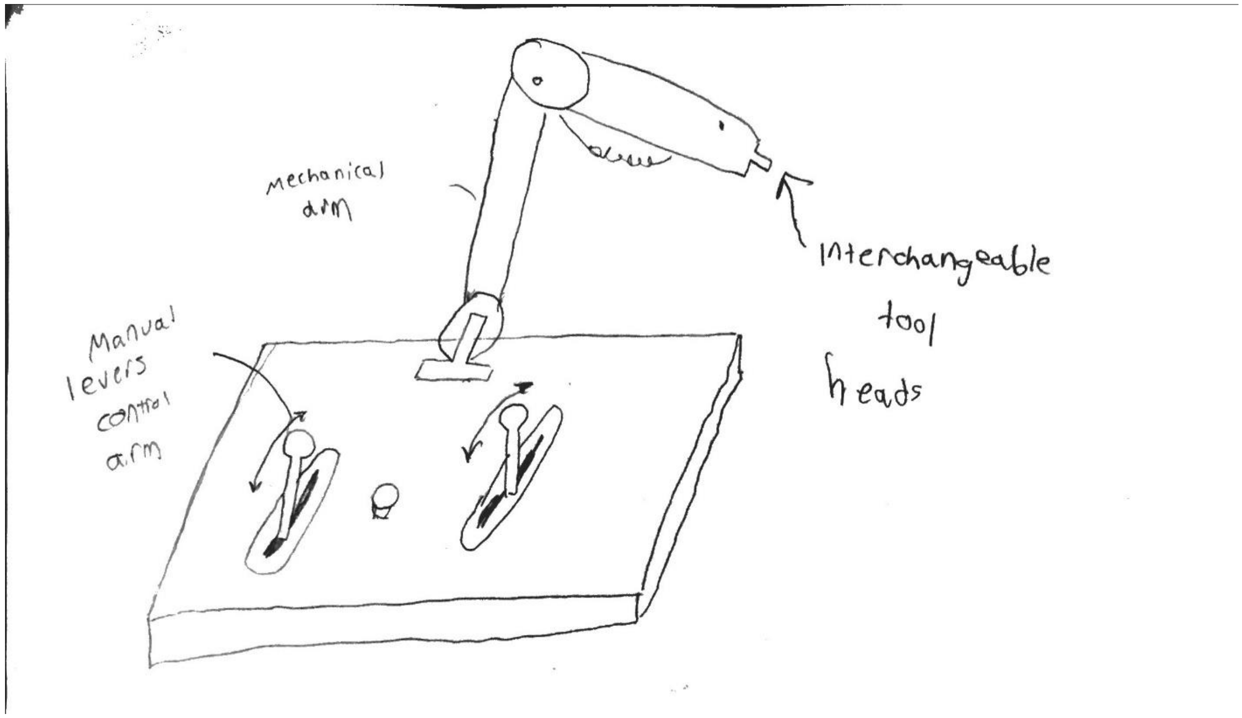

Figure 21: Mechanical Arm

This design was made up of a 2-levered box that was placed on the lap of the user and it has a long controlled mechanical arm. The Mechanical arm was controlled by the input of the user by moving the controllers on the levered box. The end of the mechanical arm can have different tools attached depending on the task that was required.

4.9 Design #9: Long-Reach Multi-Tool

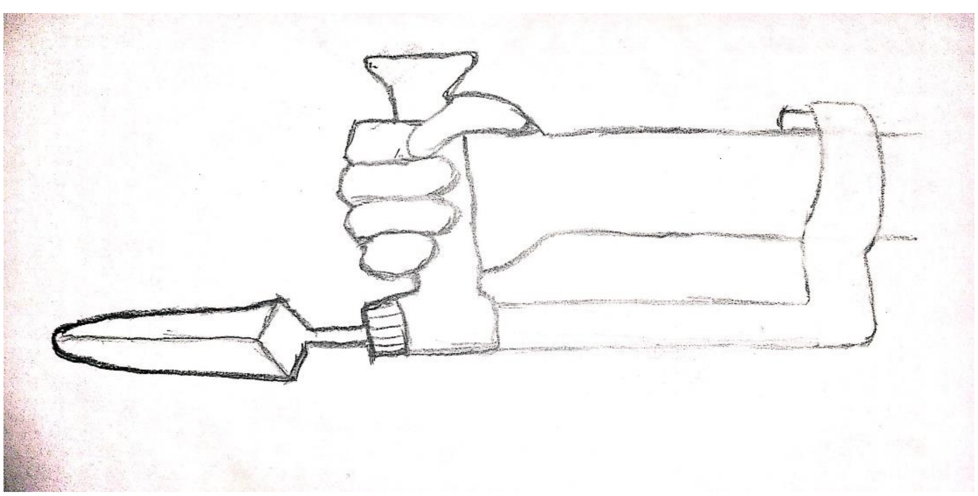

Figure 22: Long Reach Multi-Tool

This design was a hand holder that was attached to the wheelchair and assists the user to use his/her hand while gardening. A changeable head was attached at the end of the hand holder. The head was changed to give the user the opportunity to do multiple tasks depending on the attached head.

4.10 Design #10: Trimmer Copter

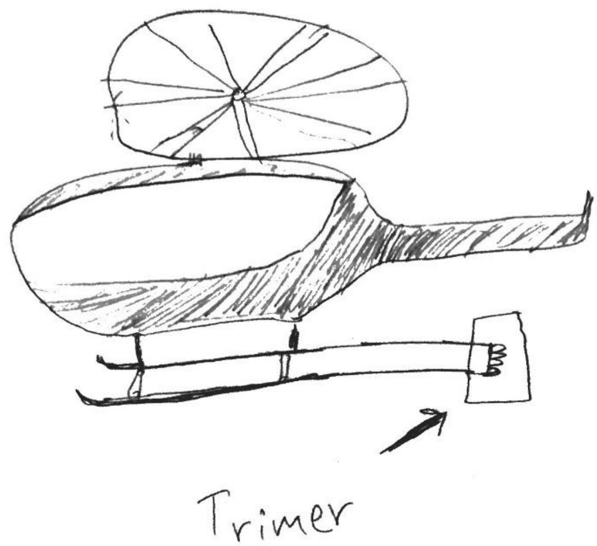

Figure 23: Trimmer Copter

This design was a bio-inspired design that depends on the movement of a small remote controlled helicopter to trim plants. The user can control the device using a remote-control device. The advantage of this design was that it can reach very far distances. However, this design lacks the potential of fulfilling more than one task and it might not be very safe to use.

5 DESIGN SELECTED

To select the design to pursue, the team created a Pugh Chart comparing the ten designs from section 4, figures 13 to 22, against a chosen datum. This chart narrowed the designs to a top three, which were then shown to the client. The client expressed strong preference for design 9, figure 21; the multi-use reach tool.

5.1 Rationale for Design Selection

The team created the Pugh chart shown in figure 24 to narrow our designs to the three most congruent with our CRs. The team chose design 8, figure 20, to be the datum because it has the most evenly distributed benefits and drawbacks. For example, its multi-use arm meets several of our CRs, but it lacks comfort and requires unacceptable amount of work input from the user. The extent to which each design met the CRs was compared against the datum; meeting the CRs more effectively than the datum would net a 1, no discernable advantage of one over the other would net a 0, and meeting the CRs less effectively than the datum would net a -1. These values were then summed, and the highest-scoring three became the team’s top picks.

	Design #1	Design #2	Design #3	Design #4	Design #5	Design #6	Design #7	Design #8	Design #9	Design #1
Safety	1	1	1	1	0	1	1	|	1	-1
Portable	1	-1	1	1	1	0	1	|	1	1
Comfortable	1	-1	1	1	1	0	1	D	1	1
Easy to Reproduce	1	-1	1	-1	1	0	1	A	1	0
Low Cost	0	0	1	-1	1	0	1	T	1	-1
Widely Applicable	-1	0	-1	-1	-1	0	-1	U	0	-1
Aesthetically Pleasant	0	-1	1	1	-1	0	-1	M	-1	1
Non-Strenous to Use	0	1	0	1	1	1	-1	|	1	1
Durable	-1	0	1	-1	0	-1	-1	|	1	-1
Quiet	1	1	1	0	1	1	1	|	1	0
Total	3	-1	7	1	4	2	2	|	7	0

Figure 24: Pugh Chart

The team took these designs to the client for approval, and any methods to further narrow the design list were made obsolete when our client showed unabashed, enthusiastic preference for design 9. Thus, the team chose for the extended multi-tool, design 9 shown in figure 21, to be our design of choice for the remainder of the project.

5.2 Design Description

This final design was a hand holder that was attached to the wheelchair and assists the user to use his/her hand while gardening as shown in figure 25.

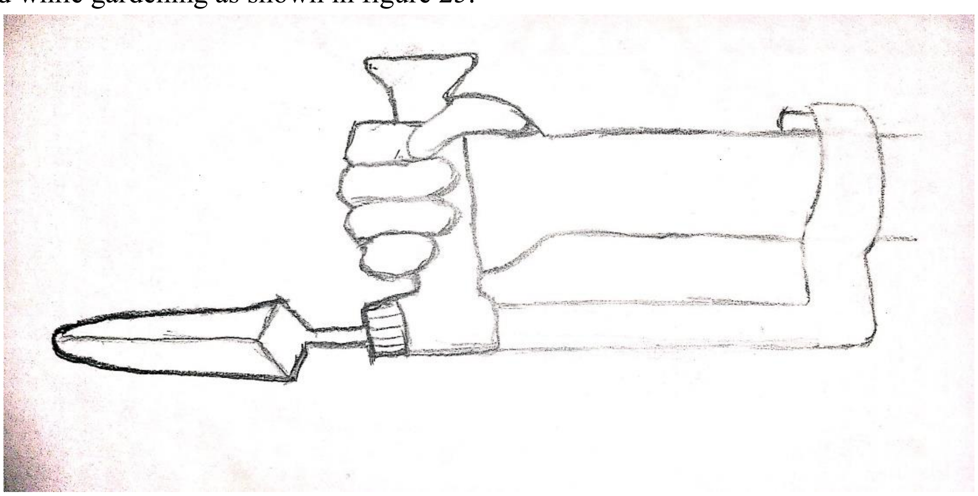

Figure 25: Final Design

A changeable head was attached at the end of the hand holder. The head was changed to give the user the opportunity to do multiple tasks depending on the attached head. This design could give the tasks needed, our goal was to create, and implement a device usable by a person living with physical disabilities to complete tasks in a garden setting. These tasks may include watering, harvesting, trimming, and planting flora along with pulling weeds or moving pots. The team's primary objective was to create a device that effectively and reliably accomplishes at least one of these tasks. This was our final design that we are going to build for the people at Hozhoni foundation because this device could reach most of the goals we want as team. Below will clearly show the details of the hand holder design as well as how it will be placed on the wheel chair for the user to be comfortable. Also, it will show how we will fit the different parts on the device and the calculation we are going to use.

5.2.1 Device-to-Wheelchair Fastener

To further improve on the design, the position of the joystick was critical. The position of the holding device determines whether the person controlling the wheelchair shall get tired or not as well as whether they will be comfortable using the grabber while holding themselves to the wheelchair. For the positioning, the team seeks to locate the holder on the left-hand side armrest of the wheelchair. The position shall be at the front most part of the wheel chair. At this point, the holder will be positioned a little inwards to the right of the armrest. All of this was shown in figure 26.

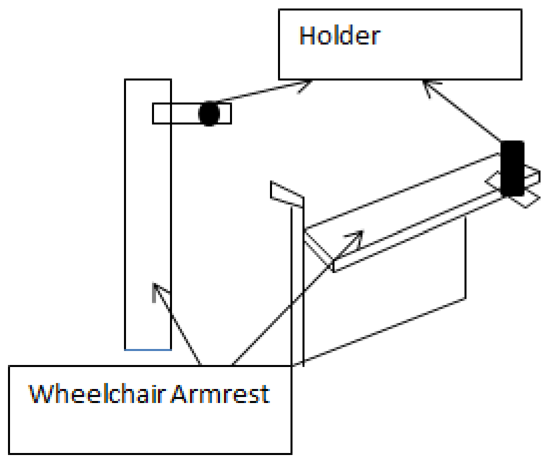

Figure 26: Device-to-Wheelchair Fastener

The reason for placing the handle on the left had side of the wheelchair was to ensure that the users can use their weaker hand to hold on to themselves and control the wheelchair and at the same time use their stronger hand to do other activities using the device. For most people, left was their weaker hand, which was where the holder will be positioned, and right was their strong hand, which was the hand they mostly use for various activities. In addition, the holder will be positioned at the front most part of the arm rest and a little inward to allow for the arm to rest on the armrest and allow for effective holding. Allowing the arm to rest on the armrest ensures that the user does not get tired while holding on to the device and controlling of the movements of the wheelchair.

The holder will be fitted on a level metallic board that was covered by plastic. The metallic board shall be fitted using crews to the wheelchair's armrest. On its right end, the holder will then be attached and fitted using screws as well. The fitting shall be covered with plastic covering to allow for safety and comfort.

To further improve the design, the team seeks to incorporate the use of holder that was designed to fit intended purposes. The holder was design in a manner that it will improve the holding abilities and handling of the movements of the wheelchair through rotating as a 360-degree angle. In addition, the design will be complex to allow for effective holding and handling of the wheelchair. Further, the design will incorporate measures that allows for protection, such as sliding of the hands while holding the holder. Also, the design will use quality materials to facilitate for quality grip as well as quality handling of the holder.

The design shall include a U-shaped top of the holder handle. The curved shape allows for the user's hand to avoid sliding off the handle while in use. In addition, the waterfall edge at the palm of the arm allows for a smooth and comfortable rest and effective holding and control of the device. The design of the holder provides comfort while having maximum control of the wheelchair.

In addition, the cover of the holder handle shall be made of a soft rubber. Rubber was known to have more grips compared to other materials. In addition, rubber usually has a spongy feel. The spongy feel will allow for comfort, where the user shall have a hard time holding the devise. Also, the rubber allows for increased grip while operating the devise. The use of the rubber covered handle was effective for individuals who have weaker hands. It helps in providing increased grip for the users, which makes them grip better compared to if it was made from other materials.

5.2.2 Tool Heads

It was after a realization of the problem the people who are handicapped are facing. This was having in mind that they are unable to do most of the tasks performed by the rest of the members of the society that we decided to take this as our project. This will help them to take part in some of the tasks in the society. The tool was more flexible due to the use of the changeable head. Different tools attached at the front will be used to perform different task hence a wide coverage design in figure 2 was the selected design based on the engineering requirements. The next step was some calculations that we are using to test our design selected to see how durable was the material of the design to hold weight and how much work do the user need to use the device. This was done using Equation 1 [6].

$$w = fx\, d \qquad \textbf{(Eq 1)}$$

based on our engineering requirements in appendix A table 1 our mass while be 100Ibs and since we are talking about the tools part which was the shovel so the force on the going to be on the user will be

$$f = \; mxg = 100\; lbs\; X\; 9.8\frac{m}{s^2} = 980\; N$$

by knowing the gravitational force and from table 1 the distance should reach 5ft long and be converting feet to meter. know we could get the work done be using Equation 2 [7].

$$w = fx\, d = \; 980N\; x\; 1.524 = 1{,}493\; J$$

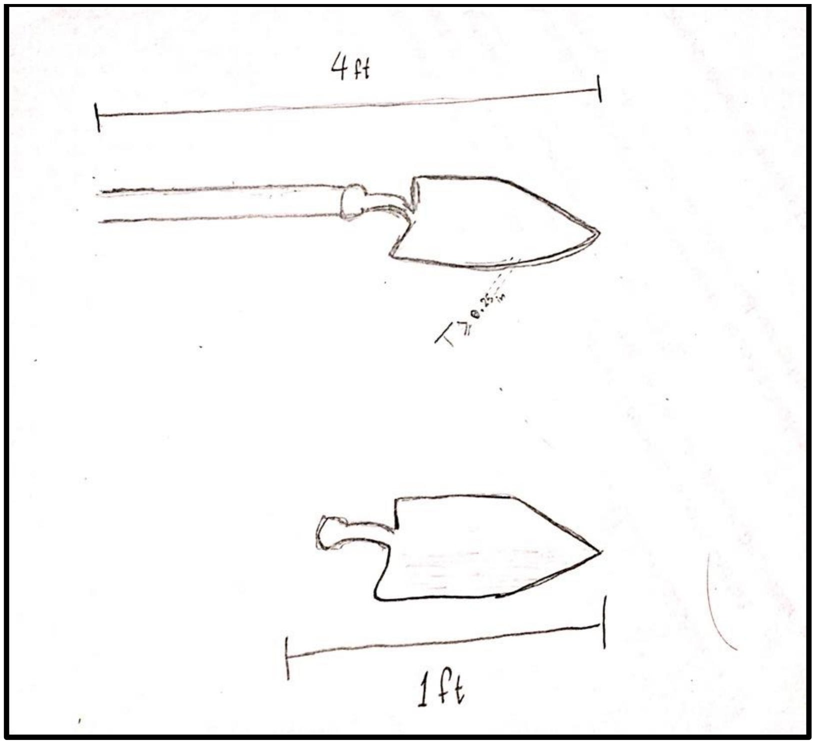

Figure 27: Shovel Measurements

After analysis, we decided to use the three tools due to their effectiveness and their necessity in the society, in the case of a trimmer with a basket, it was going to help the people to participate in harvesting of leaves and fruits. In this case the component must be long and have the capacity for adaptability since the trees cannot be of the same height. This means that the user should be able to vary the length of the tool depending on the case at hand. The trimmer with the basket as in figure 1 will be used to cut the fruit or a leave which will fall into the basket after which the user will be able to collect all the harvest from a central point.

Scooping substances using a shovel was almost a day to day activity in the society, for this reason we decided to make sure that our tool could hold a shovel at front to help the to work with it. On the changeable front was where we are going to have the shovel attached and put in place. The tool will be held by the user and he will scoop materials using it and to be sure that the user can reach many distance while he's sitting on the wheel chair so there will be two kinds of shovel long and short reached stick as in figure 27.

A rake was also a very essential tool in every homestead and can be of benefit to any person who can use it, it was for this reason that we decided to include it in our project to enable the disabled to enjoy using it in their day to day activities, the rake will be attached at the front of the tool and the user will use it just like any other person would do.

For a long time, people with disability have been viewed as a burden in the society, this was because they are not able to take part in almost every other work that was done in the society, in most cases we find that they are not taken good care of. For this reason, we found it necessary to come up with something that would enhance their participation in the activities at home which in will intern go a long way in enhancing their acceptability at home. With the project, they will be able to help doing tasks and depending on the task to be performed they will only be required to change the tool at the front.

5.2.3 Tool-to-Shaft Fastener

The team operated created several assumptions when examining the tool-to-shaft fastening component. It can be realized that most of the issues that will be evaluated in this case need to be evaluated on a technical basis especially in a mathematical basis. This was to help get the competitive advantage of some of the materials over other materials in the project. One of the assumptions that will be made in our calculation was that all the parts of the prototype have relatively the same value in exclusion of the handle part. There was a ceiling of the cost of the prototype that was to be developed. There cost of the individual parts needs to be relative to each other in relative proportions. This was to help to balance the cost of the overall prototype. The second assumptions were that the 'three holes' parts can be disintegrated from the other three parts that makes up the model. This assumption will help us make the calculations independent of the other parts. A focus on one part independent of the other parts will help to make correct judgments about the 'three holes' parts.' The third assumption was that the joinery of the 'three holes' parts to the other parts will be through a threaded lock joint. These assumptions will help make calculations that will be in depended of complex joinery mechanisms.

The equations that are needed for this part are ones that involves joints. The 'three holes' section was a section that deals with the connectivity that will be at the joinery junction for the three components that are joined to make the prototype design.

The joint variations operate based on Equation 2.

$$Y = k * x * z \qquad \textbf{(Eq 2)}$$

In the above equation, we are relating any three sides of a joint. One side was referred to as the Y and the other side was referred to as the z. This was precisely the sort of joint that we have in our case scenario. Using the information given the first thing that one should do was to find the value of the k. We can make k the subject of the above equation which results in Equation 3 [8].

$$K = \frac{y}{xz} \qquad \textbf{(Eq 3)}$$

K value was the constant value of proportionality. The constant k of proportionality will be influenced by the relative values of the lengths of the extensions from the joint junction [7]. Once the value of k has been found it was then plugged into the initial equation and any of the other variables can be deduced.

We must however realize that among the implement that we shall be using, there are other factor that plays in the joint that needs to be considered. The major one that needs to be considered was the force that was exerted on the joint. If we look at the joint when the device was being used, the major force that causes a strain on the joint was the force that was exerted by the holding arm.

The force that was exerted at this point was calculated using Equation 4 [6].

$$Ft = Fa + \frac{1}{2}MV^2 \qquad \textbf{(Eq 4)}$$

This force was a function of the mass of the whole device that we shall be making and the force that was exerted by the arm. The person that was using the tool will exert the force Fa. The other force will be provided by the force of the device which was the $\frac{1}{2}MV^2$. This force was a function of the mass of the device and the velocity with which the user of the device drives it into the ground.

Once this force has been found, it will then be evaluated based on moments that are transfers to the joint area. Equation 5 was used to calculate this moment.

$$M = F * d \qquad \textbf{(Eq 5)}$$

Moment of a force was the force multiplied by the distance. This will invariantly be the mid-length to the area where the user of the tool will be holding the implement. This length was what will be regarded as the y that will form the basis of the equation y=kzx above.

The final variable that we will need to be able to apply the above equation was the strain value for the material that will be used to make the joint. This strain value will be used as Ft and then the rest of the values will be calculated backwards until we get the value of k.

The modeling of the ‘three holes’ section will be dependent on the three facets that are going to be plugged into it. First, the three parts holes will act as the outer lock of the joints that will be made. The inner side of the three holes will have threads where the external parts will be threaded into. They will have a surface similar to the T-pipe junction shown in figure 28.

Figure 28: Three-Holed Threaded Junction [9]

The other thing about the outside characteristic was that it needs to have a curved surface. Looking at the function that the device will be playing, it needs to be safe to the user. The most user-friendly shape was a circular shape. This was because; this shape was not likely to cause an injury to the user. In the fig 1, such a shape would be ideal as there would be no scrapping of the user of the device. It should also be ensured that the surface needs to be smooth to avoid any sort of scrapping of the user of the device.

The other physical appearance feature was the relative positioning of the three holes. The three holes should be positioned as in figure 1 above. The three holes are at right angles with each other. This will help in the application of the effort that will be used to do the work. It will also help in making the worker to be comfortable as they are doing the work.

There are three different materials that need to be evaluated for use in the making of the device. We have PVC pipe, steel or wood. The first analytics will be the applicability of each of three materials to be able to work with the equations that we made earlier.

The first thing that we said was that the calculations of the 'three hoes' will be based on the tensile values of the materials.

The first evaluation was the PVC pipe. The PVC pipe that a person can hold in their arm (radius 1.5cm) will break when a strain of 260kpa [10]. In the customer requirements, it was stated that the force the weight of the device should not exceed 25lbs. This translated to about 120 Newton's. The arm provides an average of 100 Newton of pressure during the gardening. Converting this value to pressure using equation 6 yields a value the team can compare to these requirements.

$$P = \frac{F}{A} \qquad \textbf{(Eq 6)}$$

=220N/0.0007

=314 kpa

We already have that the pressure that was exerted by the arm and the weight of the device was greater than the tensile pressure for the PVC pipe. The PVC pipe was therefore a bad idea for making the three holes.

We still evaluate the tensile strength of a circular block of wood that was Wood has a tensile strength of 560kpa. This was for the Fir wood that was known to have some of the largest strength among wood. [11] In the analysis above, we have a ceiling of force that needs to be handled of 324kpa. This means that the force that the wood can withstand the pressure that was exerted by the work that was done by the implement. However, there was one disturbing factor about the wood. The factor was that the wood degenerates in its tensile strength at the rate of 60 percent per annum in high tensile pressure. There was a high pressure being applied in this case, and therefore, the wood was likely to last for only a year.

The tensile strength for a steel pipe that has the same diameter as the other two materials was 7000mka. This tensile strength was far much greater than the pressure that it was supposed to withstand of 314kpa [11]. The degeneracy of steel was 0.5 percent per annum in high pressure.

The other consideration that we may make a value comparison was the cost of using any of the above three types of materials. First, the PVC was the cheapest of the three materials with a model that can be used for the above three holes costing $30 [12]. Wood comes in next, with a model for the above three holes costing about $35 [12]. Steel was the most expensive of the three with a 'three hole' piece costing $50 [12].

Looking at the three materials, they all have a chance of being used for making the three hole' piece. However, the applicability of some of the materials cannot be encouraged based on the mathematical facts that have been found above. First, all the three pieces falls with the budget constraint. However, the fall out comes when it comes to the strains strength. PVC will give in to pressure if it was used to make the joint. This was because it has a lower tensile strength than the pressure that was expected. Wood and Steel can withstand the pressure that will be there during the use of the device. However, the wood will degenerate within a year it if it's used which brings in the question of the replacement costs. The other degeneracy point about the wood was that we need to have thread made on the three holes of the part. To be able to make inner threads that will be durable on the inner side of the wood may be a challenge though it can be done. Ii was recommended that steel was the best option for use in the making of the 'three holes' piece.'

5.2.4 Shaft Material

The Hozhoni foundation gave the team specific requirements that the team needs to follow to accomplish the required task. These requirements were interpreted, by the team, to customer requirements that were approved by the foundation. The main customer requirements are that the device must be safe to use, the device must be durable, it must be not very expensive to build and requires low effort from the individual using it. These customer requirements helped the team generate different engineering requirements that must be fulfilled by the team to ensure the functionality and quality of the final device created. These engineering requirements are many but the main requirements are that the Design's weight must not exceed 25 lbs., the cost of manufacturing must be less than $400 and the shear resistance for the materials used was less than 50 lbs. The team started brainstorming ideas for the needed device and after many comparisons between the ideas, the team finally chose a design idea that was approved by the foundation to fulfill the requirements of this project. The final design idea was simply a long reach Multi-tool device that has a hand handle for the user to rest his or her arm. One of the main advantages of this design was that it was attached to the wheelchair, which indicates that it must not exceed the required weight limit. Moreover, the design has a changeable head that gives the user the opportunity to perform different tasks by simply disconnecting the attached tool and connecting a different tool that satisfies another task. The sketch for the final design can be referred to in figure 25 on page 23.

To fulfill the stated engineering requirements, specific analysis was required for different parts of the design. In this report, analysis for the required shaft material will be conducted to reach a specific resolution that was within the costumer and engineering requirements.

Finding the most efficient material to use was a very important step in this project. Finding the material to use for the shaft undergoes a lot of specifications. These specifications include the weight of the material, cost and the ability to withstand different pressures for a long time.

One of the main analyses that need to be conducted to determine the most efficient material for the shaft was the shear stress for each material considered. This design requires a material that can withstand certain loads and pressures. The shear stress (τ) determines the durability of the material used, which was one of the main costumer and engineering requirements. Using Equation 7 [10], the shear stress for different considered materials will be calculated.

$$\tau = \frac{QV}{Ib} \qquad \textbf{(Eq 7)}$$

Where:

Q- calculated moment
V- calculated shear at section
I-moment of Inertia
b- width of beam

Moreover, pricing was also considered a very important requirement and having material that has a reasonable and affordable price was also very important. The calculated shear stress over a specific cross sectional area and the prices for different materials was shown in table 2.

Table 2: comparison between different materials

Type of shaft material	**Shear Stress (MPa)**	**Price/foot**
PVC	52	$2-4
A36 Steel	425	$5-7
Glass	33	$9-11

Per the calculated shear stress and the price/foot for each material, the A36 Steel had shear stress of 425 MPa, which increases the durability of the shaft. Moreover, the price per foot for the A36 steel was $5-7, which was considered very reasonable for the price of shaft material. The PVC was a good material, especially for prototyping; however, the shear stress was not very high which decreases the ability to withstand the pressure of continuous use. The glass was not a very good choice due to the low shear stress and high price compared to other materials. Per Table 2, it was clear that the A36 steel, which was shown in figure 29, was the most efficient and suitable material for the shaft.

Figure 29: A36 Hot Rolled Steel Round Bar [12]

Another equation that can be used for analysis was the Torque (τ) formula. Torque was simply the created force due to the rotation or movement of a device. The amount of Torque created by the movement of a material was related to the costumer requirement that identifies the amount of effort required by the user. Torque can be calculated using Equation 8 [10].

$$\tau = rF\sin\theta \qquad \textbf{(Eq 8)}$$

Figure 30 shows the variables that are used to calculate the torque.

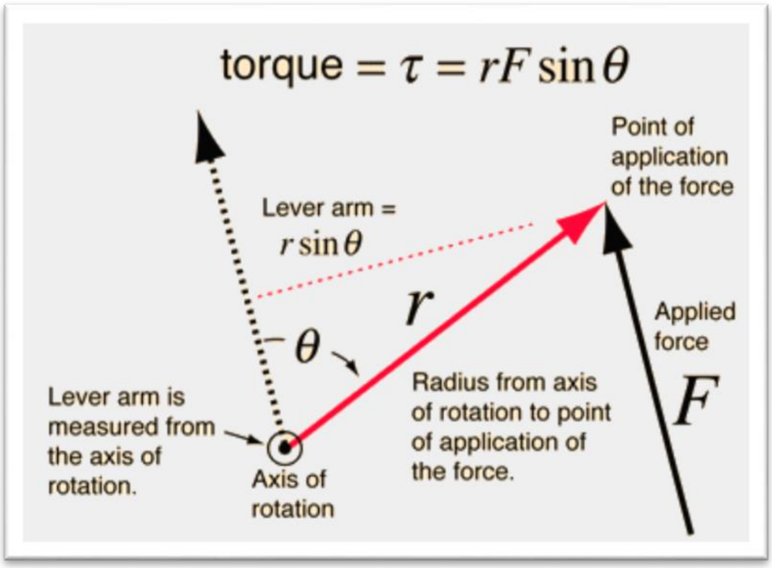

Figure 30: Torque equation explanation [10]

5.2.5 Transfer of Mechanical Energy

The final device will utilize mechanical energy from the user to accomplish tasks. This energy will be transferred along the shaft from the handle to the tool head in two forms: solid body mechanics and elastic potential. The first of these, solid body mechanics, refers to the act of using the rigidity of the shaft to extend the user's reach and accomplish mechanically simple tasks. For example, the shovel head attachment shown in figure 27 operates by accepting a load of soil and using work to move and discharge said soil. The only transfer of energy required occurs naturally as the rigid body of the shaft moves in accordance to the user's arm movements. The technicalities of this transfer lie in the shaft itself. This analysis was described in section ***5.2.4*** beginning on page 28.

The second mode of mechanical energy transfer, elastic, becomes necessary when the tool utilizes the garden clipper attachment shown in figure 31.

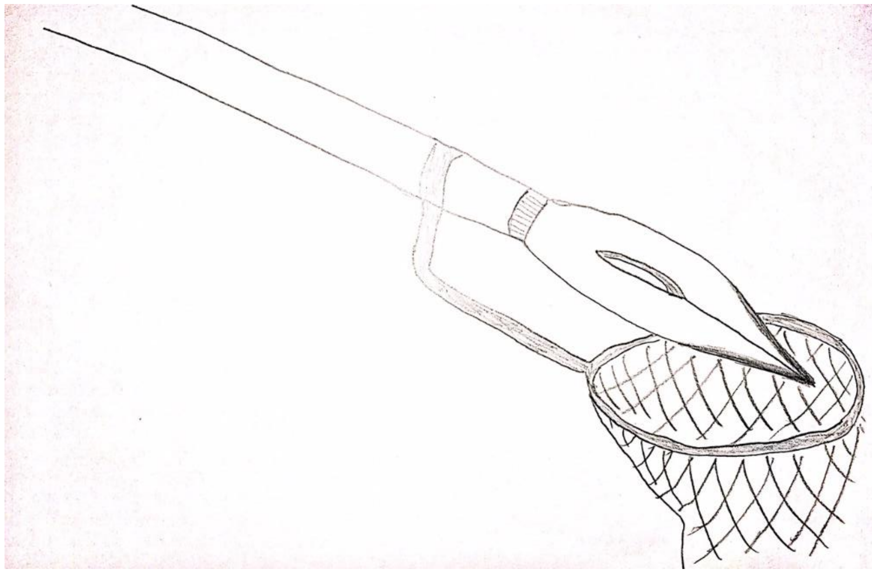

Figure 31: Garden Clipper Tool Head

For this tool to be effective, force input from the user must maneuver the tool using the solid body transfer and an additional force to open and close the shears. The team has decided to accomplish the latter by implementing a spring-and-lever device. Referring to figure 32, the highlighted areas denote where these components would be positioned.

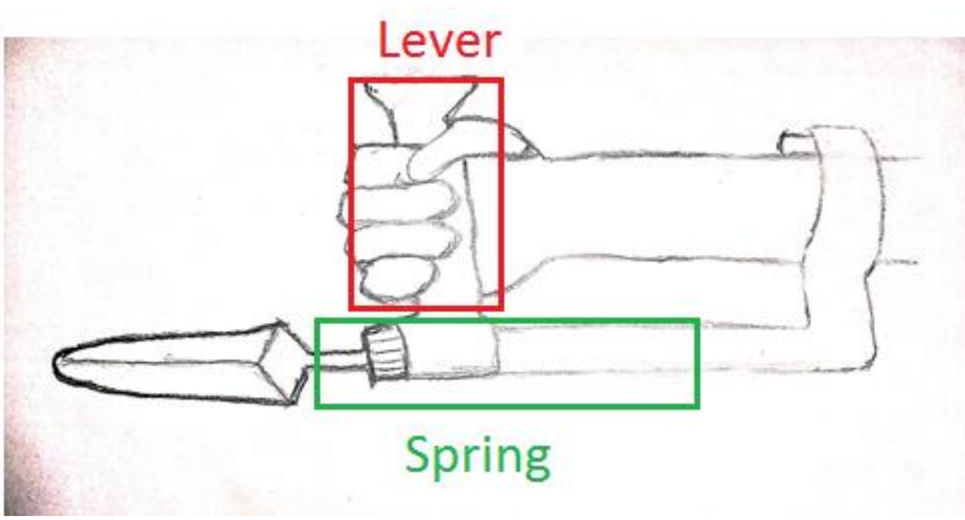

Figure 32: Spring-and-Lever Positions

The user would actuate a lever implemented into the handle to extend a spring, and the resulting linear, elastic force would actuate the jaws of the shears.

The team was designing the shears to remain in the ‘closed’ position when not in use, meaning the strength of the cutting force was determined by the magnitude of the elastic force provided by the string. This was done for two reasons. Firstly, keeping the shears forcefully closed limits potential exposure to the sharp jaws and promotes safety in accordance with the CRs. Secondly, this system would only need user input to open the jaws, at which point cutting occurs with the user simply releasing the lever. This limits the time spent actuating arm muscles which prevents arm fatigue, eases use, and makes the device more accessible to individuals with physical problems related to arm flexing.

The lever would need to be integrated into the body of the handle to remain unobtrusive and comfortable to the user. However, this means the device must translate the horizontal force from the user clenching their fingers into vertical force the spring can utilize. The process for accomplishing this was shown in figure 33.

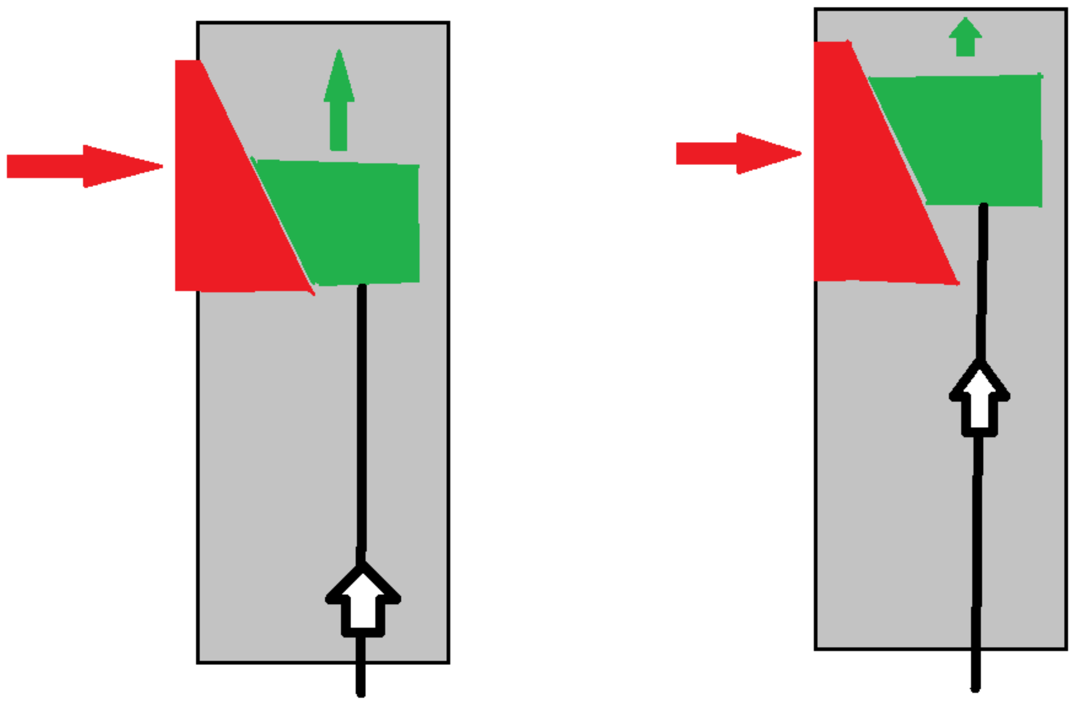

Figure 33: Lever Mechanism

The mechanism uses two wedges doing work on one another to create vertical force on a rigid bar. This bar then actuates the spring maintaining tension in the jaws as shown in figure 34.

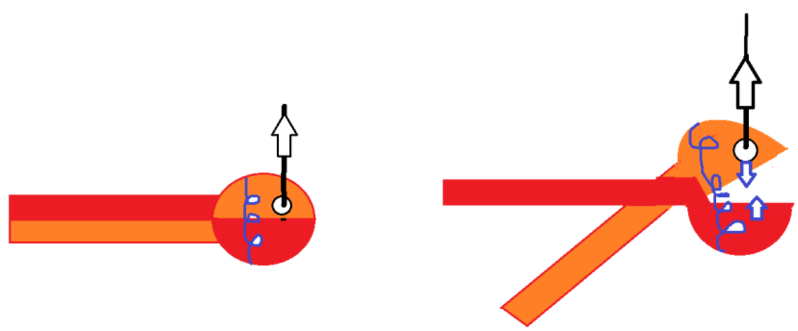

Figure 34: Spring Mechanism

A tension spring holds the scissor-like design shut. When the bottom jaw was opened, the elastic tension will force the jaws back together in a cutting motion when the force was released. Creating the entire mechanism will require more than one manufacturing process. The shears, the wedges in the lever, the tension spring, and the vertical bar must all be individually analyzed to ensure success.

The spring will need to be a tension spring, meaning a spring that resists tension and cannot be compressed in its neutral state. When extended, the tension in the spring was calculated using Equation 9 [13].

$$F = k * d \qquad \textbf{(Eq 9)}$$

Where;

F = Generated Force

k = Spring Constant

d = Displacement of Spring from its Neutral State

The generated force must be equal to or greater than the shear limit of whatever was being trimmed. The shears will be used with thin-stemmed plants, with have an average shear strength of less than 0.4 MPa [14], meaning the generated force will not need to be substantial. This was beneficial, since the displacement of the spring will be small. The displacement of the spring was proportional to the size of the jaws, which was discussed in section ***5.2.2***. Generating a small force from a small displacement will require a mid-to-low spring constant which in to turn requires a mid-to-low priced spring.

The estimated cost of the complete system was broken down in table 3. The wedges in the lever mechanism must be 3D printed of polymer material capable of withstanding the generated forces using campus resources, and a thin cylinder of a low-quality metal will serve as the vertical bar.

Table 3: Estimated Cost for Spring-and-Lever Shear System

Item	Estimated Cost
Shears	$19.99 [15]
Wedges	$29.99 [16]
Vertical Bar	$1.99 [15]
Tension Spring with Low k	$39.99 [15]

6 PROPOSED DESIGN

Once the team had chosen and fleshed out the chosen design, the next step was to determine how our device will be implemented into the Hozhoni community and how the team budget will affect said implementation.

6.1 Design Implementation

Implementing the design will be divided depending on the parts that are combined to create the chosen final design. These parts are the attached tools, the tool attachment, handle, shaft and attachment to wheelchair.

For the attached tools, the team will subject variety of materials to loading likely to be experienced by each tool and examine results on structure. The team was considering tools that are used for digging, cutting and trimming. Moreover, for the tool attachment part, the team will experiment with a screw attachment and a concentric attachment and determine which will work better and which was easier to attach. Regarding the handle, the team will prototype a variety of handle configurations and will give to user for feedback of preference. Moreover, for the shaft, as the attached tools, the team will subject cylinders of a variety of materials to loading resembling of use and examine results on structure. For the attachment to wheel chair tool, the team will experiment with different attachment tools to determine the perfect tool that will support the attached device to fully function. The team has created a computer-drafted drawing of the final device to prepare for this process. This drawing can be found in Appendix B.

Schedule was basically organizing the calendar so the team know the procedure from start researching the materials that are used to build the design until testing the design prototype and finding the failure spots to edit and rebuild the prototype design in perfect shape. The purpose of the schedule was that the team can be more prepared and planned.

Table 4: Implementation Schedule

Activity	Starting Date	Ending Date
Researching material	13 November 2016	20 November 2016
Purchasing material	28 November 2016	28 November 2016
Prototyping	4 December 2016	6 December 2016
Testing	10 December 2016	10 December 2016
Editing	11 December 2016	12 December 2016

6.2 Budget Analysis

Of each project the team must design some experiments and try to implement the ideas and test them. In addition, by the ideas of the project the team can observe the output of the design and change the input accordingly. As a project team, we must make some implementation plan for the chosen design project and manage our budget and the materials that we are going to use. For the chosen design in figure 22 we are using a stick with arm support, handle, changeable head, and a tool. For the best implementation, we must create a good prototype for our design. The team has spent excessive time to think about the materials that we are going to use for the prototyping. And after discussion the team came up with two primary materials that could be used in the prototype which are PVC pipe, and steel. In the table below there are some costs of the materials to test the prototype.

Table 5: Preliminary Budget Analysis

	Materials and maximum costs	
Design parts	PVC pipe	Steel
Stick and arm support	$4	$7
Handle	$2	$11
Changeable head(three holes part)	$2	$45
Tool	$9	$15

From table 5, we can notice that the maximum total of the PVC pipe was lower than the costs of the Steel and they are $17 and $78 Respectively.Tools costs was for a full bag of tools not by pieces. The given budget was $1500 so we should manage our budget carefully to be in the safe side. If we are using the PVC pipe we will have $1483 left from the given budget and if we are using steel, we will be left with $1428. Both materials are good and they have good price for prototyping and these prices will not affect too much on the given budget. But we will go for PVC pipe for prototyping as it was strong enough and has lower price with good quality.

The preliminary and final budget analysis will both utilize the project's bill of materials found in Appendix B.

7 Implementation

After choosing our design, the team began the manufacturing and preliminary testing of the final design. We began by experimenting with various methods of manufacturing, then performed a design of experiments to capitalize on our customer needs while staying within the parameters of the manufacturing method.

7.1 Manufacturing

The manufacturing that occurred was very simple to implement. The team has created a list of the specific needed items to complete the manufacturing process. The project consisted of two main devices added together. The two main devices were the garden device and a stand to adjust the gardening device on. Firstly, to build the main gardening device specific components were used. These components are: wooden dowel, T Junction, trowel, garden rake, rubber grip, bolt, nut and washer, padded forearm brace, blue spray paint and a Gorilla glue. A couple of devices were required to assist in the perfect manufacturing of the device such as the power drill, Circular saw and a Tape measure. The complete bill of materials can be found in appendix B.

Due to the fact that the device created by the team was not a very complex device and it was made up of simple components, there was not a specific and strict procedure that needs to be followed to complete the manufacturing of the device. However, there are main procedures that are important. The procedure steps followed by the team were as follows:

1) Measure and cut 2 ft of a wooden dowel for the shaft.
2) Shape one end of the dowel so the last inch tapers in a cone with a top surface diameter of 1.5 inches.
3) Attach shaft to one of the two parallel orifices of T-junction pipe using adhesive.
4) Measure and cut 5 inches of dowel for fore grip.
5) Repeat step (2) on new dowel piece
6) Press fore grip sheathe onto new dowel piece
7) Attach to T-junction pipe perpendicular to shaft.
8) Drill a ¾" hole through the shaft 1" from the end not enclosed in T-junction.
9) Place arm brace so bracket holes coincide with the drilled holes.
10) Insert bolt through the bracket and close with 10mm nut.
11) Press tool head into remaining T-junction orifice.

Moreover, to withstand the weight of the gardening device, using specific components the team built a stand. The manufacturing of the stand followed simple procedures. The team used a 2x2 medium desnity fiberboard as a base and set four caster rubber wheels on the bottom of the fiberboard so it could be movable and used screws to hold the wheels. After that the team put a long stick on the top of the fiberboard as the main stand for the device and made this stick stabled by drilling a long t-star lag. Moreover, on the end of the stick the team screwed a cube shape wood and used another 2 caster rubber wheels so the device could move in many directions. A computer-aided draft of the device is available for reference in appendix C.

7.2 Design of Experiments (DOE)

The team will measure our success by the reaction of its user. Because of this, the team decided to try and maximize how comfortable the device is to use. To accomplish this, the team focused on three variables: the weight of the device, the length of the device, and a Velcro strap vs. elastic, continuous band for the bicep strap. The different weights were achieved by using two different materials for the shaft: wood and steel. Each of these variables had two variations, and the team performed sixteen separate trials, two for each variation. Because comfort is difficult to quantify, the team decided to maximize the amount of time one could fully extend their arm while using the device before feeling discomfort. To prevent inaccurate results from exhausting the same candidate after each trial, each member of the team partook in four trials in a rotating fashion.

Each variable was given one of two values to reflect its state in the trial: +1 or -1. -1 represented heavier weight (steel), longer length, and an elastic band to serve as the bicep strap. +1 represented lighter weight (wood), shorter length, and a Velcro strap secured around the bicep. Table 6 shows the results of this DOE.

Table 6: DOE

Trial	**Vect**	**Weight**	**Bicep Strap**	**Length**	**Time(1)**	**Time(2)**	**Time**
1	d1	1	1	1	72.2	60	66.1
2	d2	1	1	-1	62.2	48.3	55.25
3	d3	1	-1	1	73.4	56.2	64.8
4	d4	1	-1	-1	65.4	42.2	53.8
5	d5	-1	1	1	32.5	22.3	27.4
6	d6	-1	-1	1	22.4	26.8	24.6
7	d7	-1	1	-1	18.3	14	16.15
8	d8	-1	-1	-1	26.6	27.9	27.25

The team then used this empirical data in conjunction with equations 1 and 2 to generate a coefficient of performance for each of these design variables. Positive coefficients indicate positive correlation, and negative coefficients indicate a negative correlation. These coefficients, along with the defining equation, are shown in table 7.

$$Coefficient = \frac{\sum(times\ at + 1) - \sum(times\ at - 1)}{\frac{\#\ of\ trials}{2}} \qquad \textbf{Eqn. 1}$$

$$constant = \frac{\sum times}{\#\ of\ trials} \qquad \textbf{Eqn. 2}$$

Table 7: DOE Coefficients

Weight	36.1375
Bicep Strap	-1.3875
Length	7.6125
$\boldsymbol{Time = 41.9 + 36.1375(weight) - 1.3875(strap) + 7.6125(length)}$	

Even a cursory glance at table 7 will show that the weight of the device had the greatest impact on user comfort. The length of the device also contributed to comfort, while the bicep strap made negligible difference. From the results of this DOE, the team aims to create our final design to be lightweight and of medium length. From this, the team has chosen to construct the body of the device from wood, and have a reach no longer four feet.

It should be noted that our method of experimentation relied on the user fighting directly against gravity, which may not always be the case. However, the team justifies our method by arguing our test was made under the worst possible comfort conditions for typical use, meaning normal use will be much more comfortable if the extreme is also comfortable.

8 Testing

During the yearlong Capstone project, the team worked in close conjunction with members of the Hozhoni Foundation. Every step of the design process, even before the first prototype had been built, involved members of the Hozhoni community. These steps included, but not limited to, problem definition, generating customer and engineering requirements, and in-field testing. For the latter, the team allowed members of the Hozhoni community to use our devices and provide their own, personal feedback. We then took this feedback and compared it against our generated ERs. The results of this comparison are shown in Table 8.

Table 8: ER Testing Results

Engineering requirement	Target	Rationale	Satisfied
Minimum edge thickness	= > 0.25 Inches	To allow for effective grabbing of larger objects	Yes, there were no sharp edges
Design's weight	< = 25Ibs	To allow for ease of lifting and moving it around	Yes, the weight of the device was less than the target
Reach	5 feet	To maximize on the reaching out distance between the user and items	No, the reach was decreased due to satisfy the comfort requirement because of shortening the shaft behind the handle
Maximum noise	< = 60 decibels	To avoid disturbance while in use	Yes, the device did not cause any noise or disturbance
Cost of manufacturing	< = $400	To allow for affordability and reduced maintenance costs	Yes, the budget used for building did not exceed the target
Maximum dimensions for the design	2ft by 3	For effective storage	Yes
Least possible force	< = 5Ibs	To allow for ease of use	Yes
Assembly time	< = 5mins	To reduce complication and waste of time	Ambigious, the device might take less than 5 minutes if it is semiassembled however it might take more than five minutes if it is not semiassembled.

There were some problems that the team encountered. These problems included the area of freedom for the user while functioning the device and attaching the device to the wheel chair while ensuring comfort and safety. Attaching a door hinge, which gave the user the freedom to move upwards and downwards for digging purposes, solved the area of freedom problem. Attaching the device to a separated stand rather than using a wheel chair satisfied the user by ensuring comfort and safety while functioning.

For the reach, success was expected due to the fact that certain lengths of shafts were predicted to be both long and provide a comfortable position for the user. However, the hand handle attached to the long shaft proved otherwise. For redesigning and future works, the team suggests increasing the shaft of the other side of the T-junction with increasing weight on the stand to allow for a more stabilized device. In addition, regarding the assembly time, success was expected due to the initial ideas of attaching the device on a wheel chair. However, the change in plan and attaching the device on a separated stand resulted in the need of more assembly time. Having the stand assembled and semi assembling of the device would take the user less assembly time for assembling the main device and attaching it to the stand.

The final design was deeply rooted in the recommendations provided to the team by the members of the community after each testing session. By the project's conclusion, the team had produced nearly a dozen prototypes of varying lengths, shapes, materials, and variations of several components. The crux of the final design was the implementation of a hinge between the arm brace and the fore grip, something the team would not have come up with had we not worked with the community. The hinge allowed for a greater degree of freedom between the user's elbow and forearm, making the device much more comfortable and less awkward to use. The final device is pictured in figure 35.

Figure 45: The Final Device

9 Conclusions

We concluded our engineering capstone project by performing a final, post-mortem analysis. The purpose of this analysis was to examine every action we took over the course of this year-long endeavor and determine, in the simplest terms, what worked and what did not.

9.1 Contributors to Project Success

One of the first steps we took as a team was the drafting of a team charter. This charter established ground rules for conflict resolution, team member expectations, and rotating hierarchy. While the last of these ultimately fell out of practice, the first two were adhered to the letter. We spent a great amount of time as team discussing possible setbacks, chief among these being language barriers and cultural differences, and addressed all of them as we drafted the charter. The unintentional result of this a heavy emphasis on communication, definitely more than had we not had these difficult conversations. This was the main benefit offered by the team charter. Conflict resolution never became an issue, every member performed competently in accordance with the charter's expectation.

The largest contributor to our success, by a large margin, were the enthusiastic contributions of members of the Hozhoni Foundation. The individuals we worked with served as in-field product testers, and they offered countless items of insight given their unique perspective of living with physical disabilities. Their input lead to constant improvement as ERs were revised and prototypes were redesigned, and their enthusiasm for our project helped a great deal with motivation and decision making.

We as a team believe our interactions with the Hozhoni members gave us a new perspective on what it means to be an engineer. There are so many things we able-bodied people take for granted, such as our ability to open a door or plant a flower without requiring additional human assistance. Using our technical skills to remove that barrier and seeing the looks of joy and liberation on our customers' faces is an incredibly uplifting and fulfilling experience we could not have had with another project. In layman terms, our success in this project grounded us by reminding us of the important role engineers can play and what kind of differences we can make to our fellow humans. That sense of purpose and accomplishment was an additional factor that greatly contributed to our success.

9.2 Opportunities/Areas for Improvement

Although we consider this project to be a success, there are definitely oppurtunites to improve our device. Such shortcomings are the inevitable result of all engineering projects. Our greatest disadvantage was a lack of appropriate tools. All team members were full-time engineering students with no source of income to speak of, meaning all assembly and cutting was done by hand. It was a slow and difficult process, and the team was often force to borrow a peer's tools to accomplish more difficult tasks like drilling or shaping. Although we overcame these disadvantages and created a successful product, additional features such as adjustability or custom fitting would have been possible under different circumstances.

Another challenge the team faced was its lack of technical diversity. All members were mechanical engineering students of nearly identical academic background, meaning we were limited to a relatively small pool of knowledge and skills. Further efforts should consider including individuals of different academic backgrounds, such as electrical engineers, to bolster the team's knowledge foundation and lead to more technically complex product.

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APPENDICES

Appendix A

House of Quality

Customer Requirements / Engineering Requirements	Weight	Maximize Edge Thickness	Minimize Weight	Maximize Tensile Strength	Maximize Shear Resistance	Maximize Reach	Maximize # of Tasks	Minimize Reflectivity	Minimize Noise	Minimize Cost of Manufacturing	Minimize Power Usage	Minimize Dimensions (in use)	Minimize Dimensions (storage)	Minimize Input Force from User	Maximize Battery Life	Minimize Assembly Time
Safety	1	6	6	3	3	-3	0	3	3	0	0	3	0	3	0	0
Portable	7	3	6	3	3	-6	0	0	0	0	0	6	6	0	0	0
Comfortable	2	6	6	0	0	-3	0	6	6	0	0	3	0	6	0	0
Easy to Reproduce	5	0	3	-3	-3	0	0	0	-3	6	0	3	3	0	-3	-6
Low Cost	3	0	-3	-6	-6	0	0	0	0	6	-3	3	3	0	-3	0
Widely Applicable	8	0	3	0	0	6	6	0	0	0	0	0	0	6	0	3
Aesthetically Pleasant	10	0	0	0	0	-3	0	6	6	-6	0	6	6	0	0	-3
Non-Strenous to use	4	3	6	0	0	-3	0	0	0	0	0	3	0	6	0	0
Durable	6	-6	-6	6	6	-3	0	0	0	-3	0	3	3	0	0	0
Quiet	9	0	0	0	0	0	0	0	6	0	3	0	0	0	0	3
Targets		0.25 in	25 lbs	100 lbs	50 lbs	4 feet	2 tasks	ρ = 0.2	30 db	$400	12 V	3 ft^3	2 ft^3	5 lbf	30 min	2 min
Tolerances		>0.25	+/- 5	+/-20	+10	+/- 1	+/-1	<0.2	+/- 20	+/-100	-6V	<3	<2	<5	+/-15	+/-1
Testing Procedure (TP#)		2.3.1	2.3.2	2.3.3	2.3.4	2.3.5	2.3.6	2.3.7	2.3.8	2.3.9	2.3.10	2.3.11	2.3.11	2.3.12	2.3.13	2.3.14
Design Link (DL#)		2.4.1	2.4.2	2.4.3	2.4.3	2.4.4	2.4.5	2.4.6	2.4.7	2.4.2		2.4.4	2.4.4	2.4.8		2.4.7

Appendix B

Table B-1: Bill of Materials

Product	Quantity	Price	Source
1” diameter wooden dowel	3 ft	$7.68	HomeCo
PVC 1” diameter T-Junction	1	$2.69	Home Depot
6” trowel with ¾” diameter grip	1	$4.96	Home Depot
5” garden rake with ¾” diameter grip	1	$9.87	HomeCo
1” diameter rubber grip	6 in.	$10.26	HomeCo
10mm bolt	1.2 in.	$1.69	HomeCo
10 mm nut and washer	1	$1.02	Home Depot
Padded Forearm Brace with 10mm bracket	1	$12.49	Amazon
Gorilla glue	1 bottle	$4.89	HomeCo
Medline Crutch Replacement part kit	1	$8.70	Amazon
Crutcheze Forearm Crutch Pads, Covers for Arm Cuffs	1	$29.99	Amazon
MEDIUM DENSITY FIBERBOARD	1	$7.48	Home Depot
10 2 in. x 2 in. x 35 in. Baluster Redwood Square End	1	$2.67	Home Depot
4 in. x 4 in. x 10 ft. Prime #2 and Better Douglas Fir Lumber	1	$11.52	Home Depot
11 2-1/2 in. Soft Rubber Swivel Plate Caster with 100 lb. Load Rating	2	$5.87	Home Depot
12 #10 1-7/16 in. Phillips Wafer-Head Self-Drilling Screw 1 lb.-Box (108-Pack)	1	$6.85	Home Depot
13 2 in. Soft Rubber Swivel Plate Caster with 90 lb. Load Rating and Side Brake	4	$3.98	Home Depot
14 5/16 in. x 4 in. Powerlag Hex Drive Washer Head Zinc Coated Lag Screw	1	$0.59	Home Depot
15 1/4 in. x 4 in. Powerlag T-Star Drive Washer Head Yellow Zinc Coated Lag Screw	1	$0.46	Home Depot
16 #10-24 x 1-1/4 in. Phillips Flat-Head Machine Screws (5-Pack)	4	$1.18	Home Depot
Total		$134.84	

Appendix C

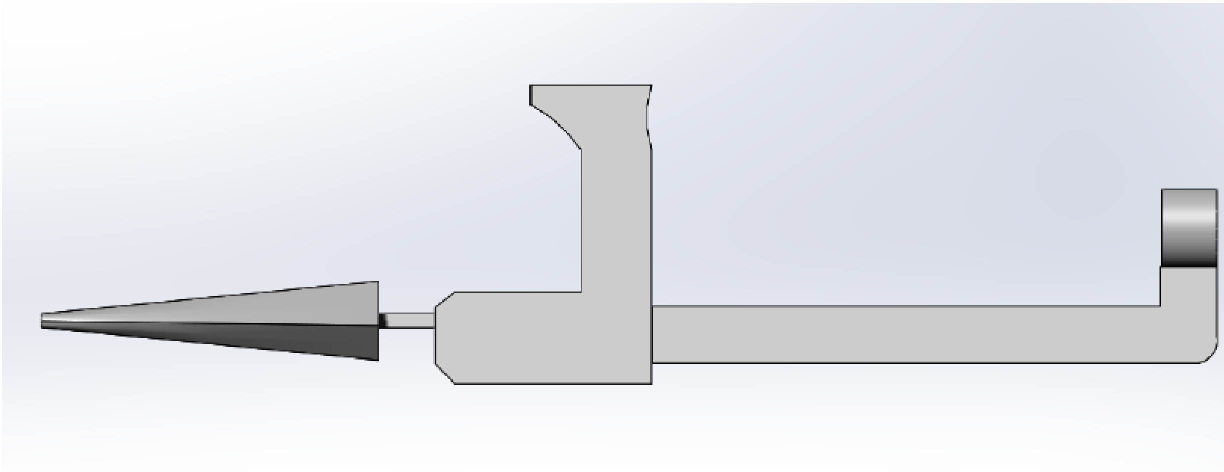

Figure C – 1: Solidworks Rendering of Preliminary Design

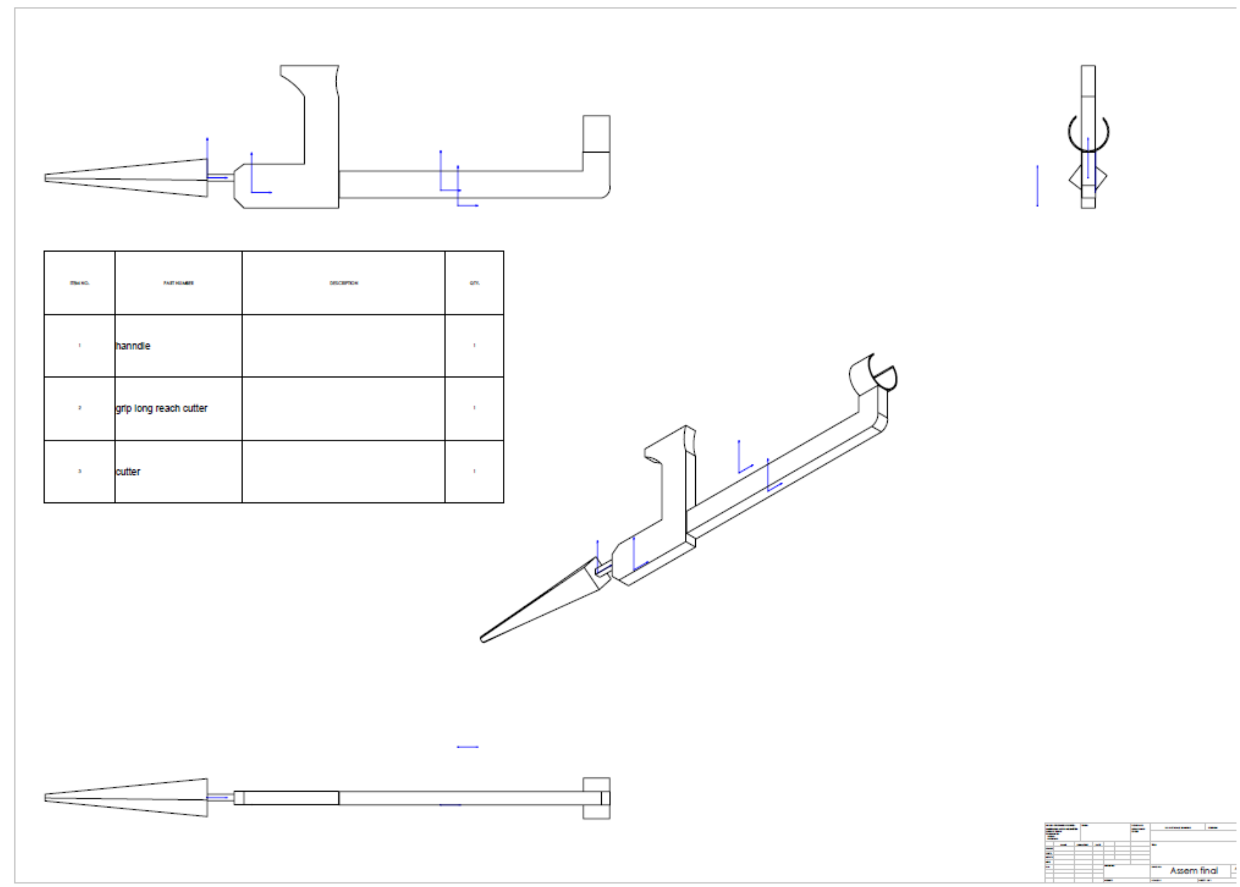

Figure C – 2: Solidworks Drawing of Preliminary Design

Figure C – 3: Solidworks Rendering of Final Design