Palm Print: Portable 3D Printer

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Abstract

In recent years, additive manufacturing, also known as 3D printing, has become wildly popular as 3D printers are becoming more accessible to the consumer. 3D printing allows users to create intricate designs which would not normally be created by traditional means. Since 3D printing is done in layers, it is typically seen as more efficient compared to machining, where you would have to remove material. 3D printing could be used with a variety of materials such as plastic, metal and resin across different sectors from the medical to the food industry. As convenient as 3D printers are right now, there are not many alternatives to portable ones, especially ones you can put into your bag. In this project, our team will be looking into designing a compact model that can easily fit into a backpack.

Keywords: 3D printer, portable, compact, PLA

1.0 Introduction

3D printing has been around for many years, but it was not until recently that 3D printers became more consumer friendly. In this section, the history, and the different types of 3D printers such as stereolithography (SLA), fused deposition modeling (FDM), and selective laser sintering (SLS) will be discussed.

1.1 History

The earliest form of 3D printing can be traced back to 1981, when Dr. Hideo Kodama "invented one of the first rapid prototyping machines that created parts layer by layer, using a resin that could be polymerized by UV light." In 1986, Charles Hull filed a patent for stereolithography (SLA). He is known as the "inventor of 3D printing," because he created the SLA and STL format, which is the format still used today (Chapman). In 1988, a student from the University of Texas, Carl Deckard, licensed selective laser sintering (SLS) technology, a type of 3D printing that uses a laser to sinter powdered material into solid structures. A year later in 1989, Scott Crump patented fused deposition modeling (FDM). Within the same year Hull's company, 3D System Corporation, released the SLA-1 3D printer (Chapman).

1.2 Stereolithography (SLA)

SLA is the old type of 3D printing. This type of 3D printing works by "exposing a layer of photosensitive liquid resin to a UV-laser beam." The object is formed layer by layer and then hardens in the desired shape. The downside to SLA printing is that once the print is completed, the object must be rinsed with a solvent and then dried in a UV light to finish the curing (sometimes optional) (Types of 3D Printing).

1.3 Fused Deposition Modeling (FDM)

The most common type of 3D printing is FDM. This type of 3D printing consists of a platform, extrusion nozzle and a control system. The filament is melted and then deposited in a x and y coordinate system (or polar) and built by layers moving in the Z-axis. This type of 3D printing is the most cost effective and efficient way to 3D print for both consumers and small businesses (Types of 3D Printing).

1.4 Selective Model Sintering (SLS)

SLS is a type of 3D printing that uses a laser to solidify and bond grains of plastic, ceramic, glass, metal, or other materials into layers to produce a 3D object. The laser traces the pattern into the bed of powder, the bed lowers, and another is traced and bonded on top of the previous layer. One benefit of SLS printing is that it does not need to generate support structures compared to SLA and FDM 3D printing (Types of 3D Printing).

2.0 Background

In the previous section, we talked about the variety of 3D printers, but for this project FDM 3D printers will mainly be discussed. In this section, the different types of FDM 3D printers (Figure 1) along with the various components that make up a FDM 3D printer will be reviewed.

2.1 Types of FDM 3D Printers:

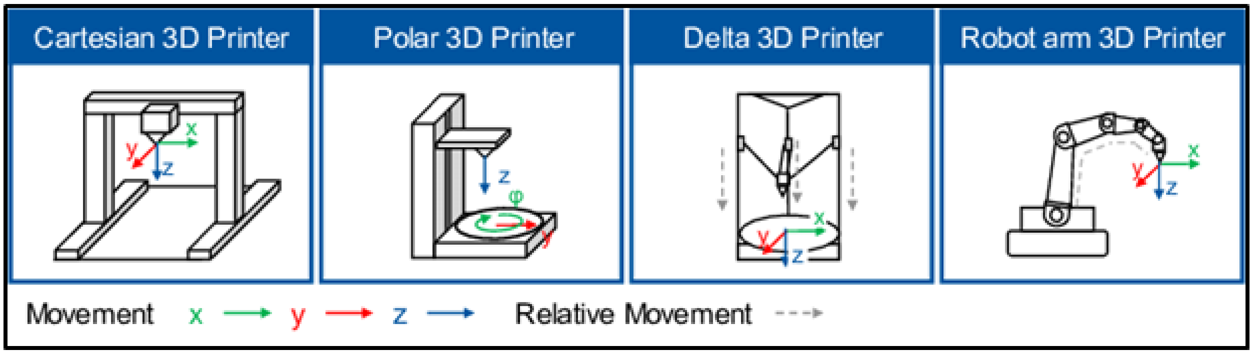

Figure 1. Types of FDM 3D Printers

2.1.1 Cartesian

The most common type of FDM 3D printers is Cartesian. The Cartesian coordinate system is a rectangular system that uses three mutually perpendicular axes, x, y, and z, to define a point in three-dimensional space. Each axis is equipped with a linear actuator that enables the precise movement of the extruder nozzle in each direction. The x-axis is typically oriented horizontally, the y-axis vertically, and the z-axis perpendicular to the printing surface.

One significant advantage of Cartesian 3D printers is their widespread availability, as many 3D printers utilize the Cartesian coordinate system. This system is supported by various online resources, such as pronterface.com, where users can access relevant code to operate their Cartesian-based printers

2.1.2 Polar

The Polar coordinate system is an alternative solution to describing 3D space for 3D printing. While the Cartesian system is rectangular and uses three mutually perpendicular axes (x, y, and z) to specify a point in three-dimensional space, the polar coordinate system uses two values, radial distance and angle, to specify a point in two-dimensional space.

In a polar coordinate system, a point is defined by its distance from a fixed point called the origin and the angle it makes with a fixed reference line, usually the x-axis. The radial distance is measured in units such as millimeters or inches, while the angle is typically measured in degrees or radians. By specifying these two values, the position of a point in two-dimensional space can be precisely defined. For use in 3D printing, another axis would be added perpendicular to the established plane. The axis is commonly referred to as the z axis.

The polar coordinate system's benefits include reduced footprint compared to alternative coordinate systems.

2.1.3 Delta

The delta system works by using the three arms, which are each connected to stepper motors, to precisely control the position of the moving platform that holds the extruder nozzle. By varying the length of each arm, the platform can be precisely positioned in three-dimensional space, enabling the printer to create intricate shapes and geometries.

The delta coordinate system differs from the Cartesian system in that it relies on the movement of a single platform, rather than individual linear actuators along each axis. This makes it well-suited for printing large objects quickly and efficiently, as the moving platform can cover a larger printing area in less time than a Cartesian system.

However, the delta system can be more complex to calibrate and set up compared to the Cartesian system. Additionally, it may not be as precise for certain applications that require very fine control over the positioning of the extruder nozzle.

2.1.4 SCARA (Robotic Arm)

SCARA (Selective Compliance Assembly Robotic Arm) 3D printers (Figure 1) uses a print head attached to an "articulated arm." In theory, the articulated arm has a higher degree of mobility and with this can create more complex designs. Currently, this type of 3D printing is not available to the public (Flynt).

2.2 Components of a 3D Printer

2.2.1 Frame

The frame of a 3D printer is a rigid structure that provides support and stability to the various components of the printer during the printing process. Typically made of aluminum or steel, the frame is designed to minimize vibrations and distortion, ensuring high precision and accuracy of the printed parts. The frame must also be able to accommodate the movements of the printer's components, such as the print bed and extruder, while maintaining their relative positions to achieve the desired print quality. The design of the frame depends on the specific requirements of the printer, including the size of the print bed, materials being used, and desired printing speed and accuracy. A well-designed and constructed frame is crucial to achieving high-quality prints and reliable performance of the 3D printer.

2.2.2 Controller Board

The controller board of a 3D printer is the "brain" of the printer that receives input signals from the host computer and translates them into output signals that control the various components of the printer. It includes a microcontroller and firmware to interpret the signals and sensors to monitor the printer's status. The main function of the controller board is to precisely control the movement and positioning of the extruder and print bed, as well as regulate the flow of filament and other printing parameters. It also provides important safety features, such as thermal and overcurrent protection. A well-designed and properly functioning controller board is crucial for achieving high-quality prints and ensuring safe and reliable operation of the 3D printer.

2.2.3 Stepper Motors

A stepper motor is a type of motor used in 3D printers to precisely control the movement and position of the printer's components. It works by converting electrical signals into precise rotational motion, allowing for very precise control of the printer's movements. The motor is controlled by the controller board, which sends electrical signals to the motor's coils, controlling the speed, direction, and position of the motor. Stepper motors come in various sizes and types, with step angle and torque being important factors to consider when selecting a motor.

2.2.4 Belts

Belts in 3D printers are used to transmit rotational motion from the stepper motor to the printer's components, such as the extruder and print bed. They are typically made of a flexible material, such as rubber or plastic, and are tensioned correctly to prevent sagging or stretching. Toothed belts are the most commonly used type and ensure precise and consistent motion.

2.2.5 Lead Screws

A lead screw is a threaded rod that converts rotational motion into linear motion in 3D printers. It is attached to a stepper motor and moves through a nut attached to a moving component of the printer. Lead screws are used in 3D printing for precise control over the position of components, particularly for the Z-axis.

2.2.6 End Stops

An end stop is a switch or sensor used to detect the physical limits of a 3D printer's movements. It triggers when a component reaches its maximum or minimum allowed position, sending a signal to the printer's controller board to stop motion and prevent damage. End stops also help with calibration by providing reference points for the printer's movements..

2.2.7 Power Supply Unit (PSU)

The power supply unit (PSU) as the name suggests, supplies power to the entire system. Usually, the PSU is mounted to the frame, but it could also be housed in a separate controller box with the user interface (Flynt).

2.2.8 Print Bed/Surface

The print bed is the surface on which the object is built in a 3D printer. It is typically made of materials like glass or aluminum, and is heated to prevent warping or detachment. Its function is critical to the printing process, as it provides a stable and heated surface for proper adhesion of the printed object.

2.2.9 Print Head

A print head, also known as an extruder, is a critical component of a 3D printer that melts and deposits the filament material layer-by-layer to create the printed object. The print head typically consists of a hot end that melts the filament material, a nozzle that controls the flow of the melted material, and a cooling fan that solidifies the material as it is deposited.

The print head's function is to precisely control the flow of the melted material and deposit it onto the print bed in a manner that creates the desired object shape. The speed and temperature at which the material is extruded can be controlled through software, allowing for fine-tuned adjustments to the printing process. The print head can also be outfitted with multiple nozzles for printing with multiple materials or colors simultaneously.

In summary, the print head is the component of a 3D printer that melts and deposits the filament material layer-by-layer to create the printed object. Its function is to precisely control the flow of the melted material and deposit it onto the print bed in a manner that creates the desired object shape.

2.2.10 Filament Feeder

The filament feeder is a component of a 3D printer that feeds the filament into the print head. It includes a motor, a drive gear, and a guide tube. Its function is to maintain a precise and consistent flow of filament material for high-quality and accurate printing.

3.0 Competitors

In this section, the current alternatives to foldable and/or compact 3D printers will be talked about and the advantages/disadvantages to each.

3.1 Cartesian 3D Printers

3.1.1 Fokoos Foldable 3D Printer

The Fookos Foldable 3D printer (Figure 2) is an extremely competitive portable 3D printer on the market today. It uses a patented design with a foldable arm which is actuated using a CoreXY system. The print head of this printer is capable of two degrees of motion, which include up and down as well as side to side movements. The print bed has one degree of motion and can move forward and backwards. With a print volume of 235*235*250mm, this printer offers a larger print area compared to our team's design requirements. Noteworthy design features include the use of four screws to secure the arm in the vertical position and the innovative folding arm that collapses past the electronics.

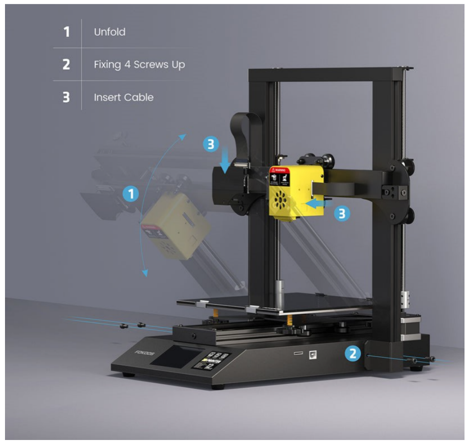

Figure 2. Fokoos Foldable 3D Printer

3.1.2 Felix Pro 3D Printer

The Felix Pro 2 3D printer (Figure 3) has an innovative folding design in which the bed can rotate 90 degrees. This design stands out because of its compact and rigid frame, for a collapsible 3D printer. One downside to this printer is the width of the printer. The team's goal was to design a printer which can fit easily into a backpack among other things, therefore this printer is too wide for our team's requirement.

Figure 3. Felix Pro 3D Printer

3.1.3 Positron 3D Printer

The Positron 3D Printer (Figure 4) stands out due to its printing upside down. This concept is unique and notably it can be taken apart to fit in the small box alongside it. The use of the coreXY system also speaks to its abundance. The downside to this 3D printer was that the process of taking it apart each time for transport is quite tedious. Our team's goal was to design a printer easy to use and set up within seconds.

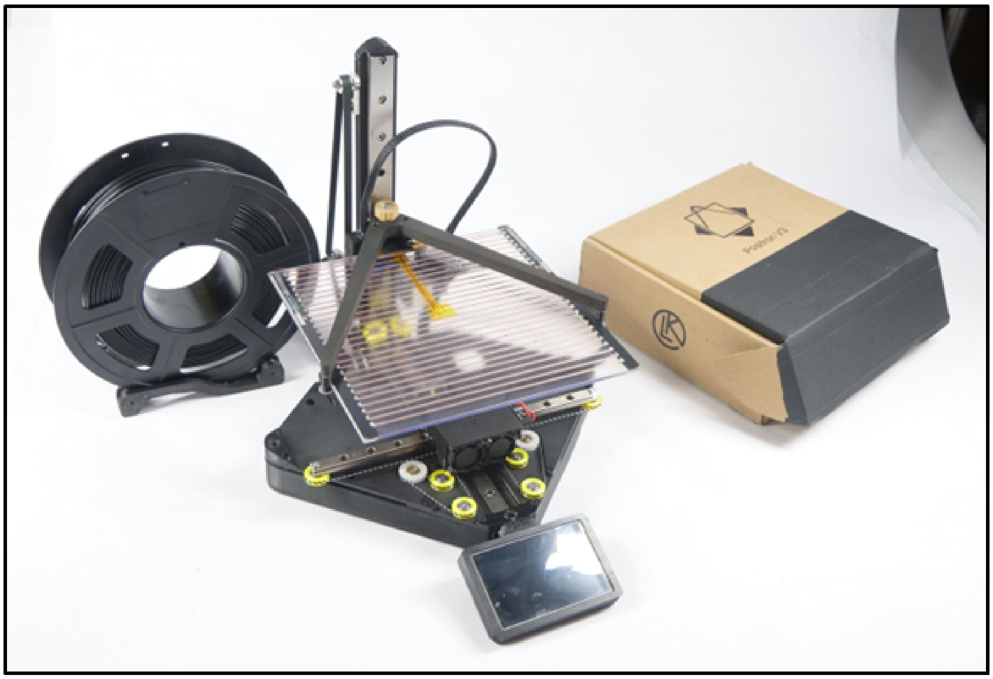

Figure 4. Positron 3D Printer

3.1.3 PocketMaker 3D Printer

The PocketMaker 3D printer is an extremely compact printer that fits into the palm of a hand (Figure 5). As this is our team's biggest requirement we took note of this printer. One thing to note was that the printer was not able to collapse in any way. Therefore, it would not have fit as nicely into a student's backpack without it being awkwardly placed.

Figure 5. PocketMaker 3D Printer

3.2 Polar 3D Printers

3.2.1 Sculpto2 3D Printer

The Scuplto2 3D printer (Figure 6) is the flagship product of the polar 3D printer market. This printer has a small footprint as well as a compact base. These features seem to be designed with portability in mind, considering the handle on top of the z axis, for easier handling. The downside is, similar to the PocketMaker, the Z-axis does not collapse.

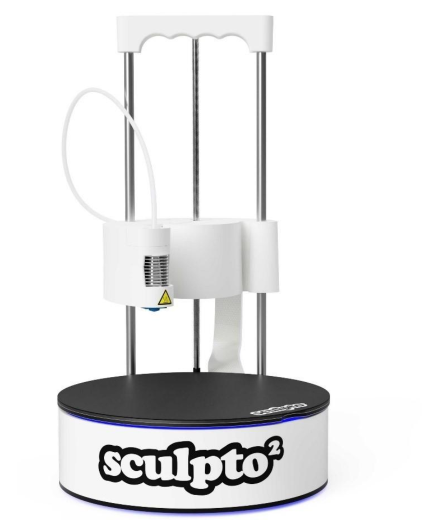

Figure 6. Sculpto2 3D Printer

3.2.2 Polar3D 3D Printer

The Polar3D 3D printer (Figure 7) uses a uniquely configured polar coordinate system. Unlike the Sculpto2, this printer has one degree of freedom got the nozzle and two degrees of freedom in the base. This reduced the complexity of the z axis, an important factor when considering a collapsible design. This printer, as the Sculpto2, puts emphasis on portability with a small footprint and a handle on the top of the arm.

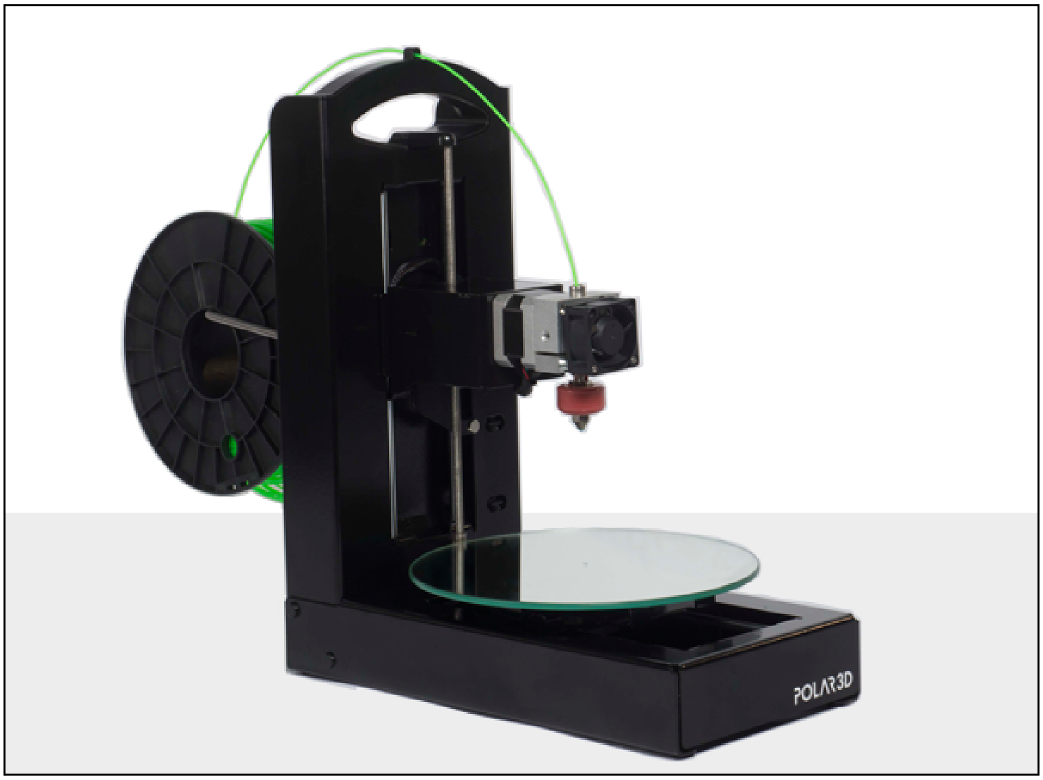

Figure 7. Polar3D 3D Printer

3.3 Unique 3D Printers

3.3.1 Pocket 3D Printer

The pocket 3D printer was an idea that hit Indiegogo with the hopes of it becoming a product (Figure 8). Although this concept was never realized, its unique articulation sparked discussion among our team. The complexity of this design most likely kept it from being realized. This printer embraces an industrial robot design which require extremely complex programming.

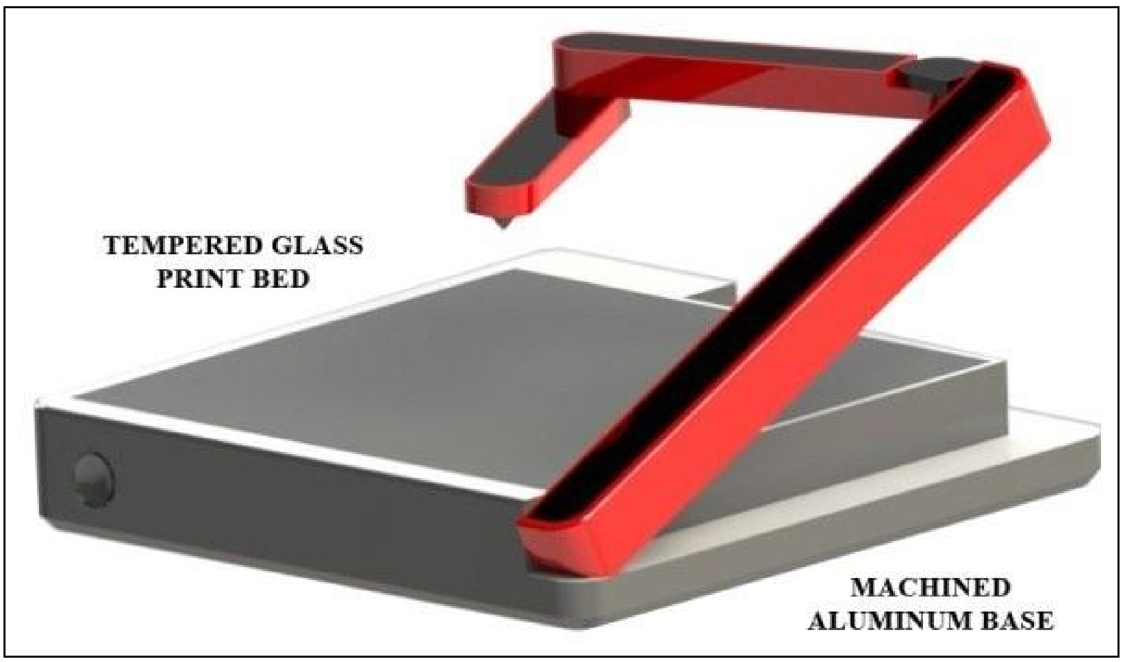

Figure 8. Pocket 3D Printer

3.3.2 Baby Belt 3D Printer

The Baby Belt 3D printer is an open-source 3D printer by Rob Mink (Figure 9). This design was unique because the object was printed on a belt while the hot end is on a diagonal arm. This concept is very unique in the 3D printing space. Similar to the Pocket 3D Printer, this design requires complex code and considering the limited possibility of part designs this concept served as a spark of creativity rather than a serious design consideration.

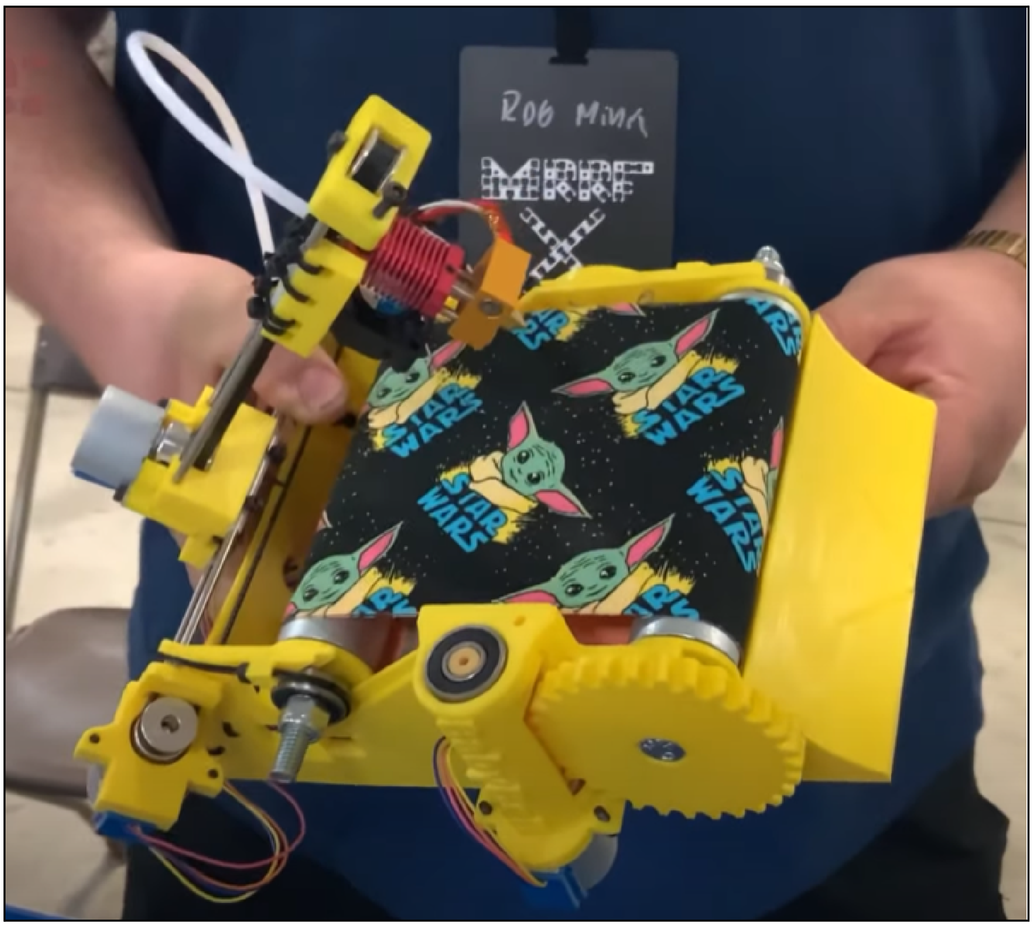

Figure 9. Baby Belt 3D Printer

3.3.3 DIY 3D Printer

This DIY 3D printer was designed by the YouTube channel, TecH BoyS ToyS (Figure 10). It consisted of CD drives for the x and y movement and a small stepper motor for the Z-axis. The use of CD drives provided a complex xy movement concept in which the bed would extend past the base. This made for a compact bed and base design.

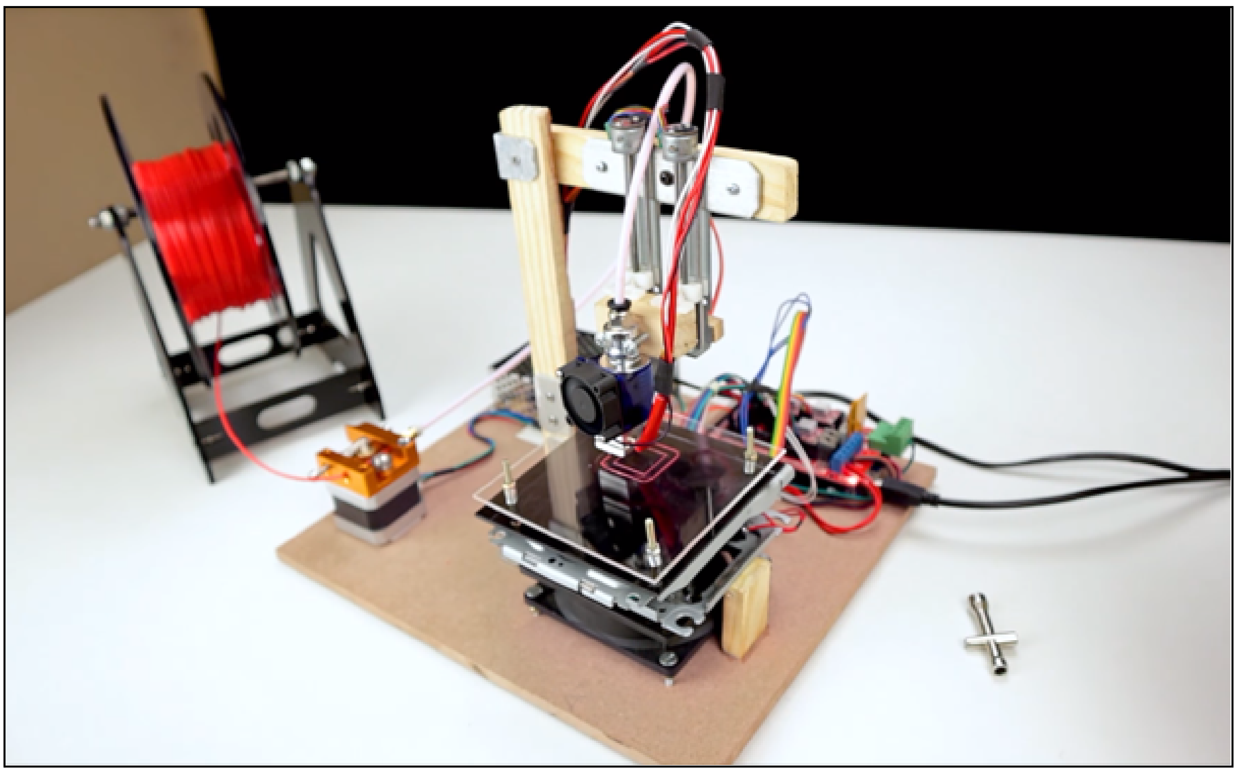

Figure 10. DIY 3D Printer

4.0 Ideation

4.1 Mind Map

The mind map in Figure 11 details the major ideas the team took from our research. As discussed previously the main focus of the design was portability. This sparked many ideas ranging from a telescope mechanism to a folding mechanism utilizing origami folds. Other noteworthy facts were included as well, such as the concept of a transport mode. "Transport mode" refers to a state in which the printer is unable to print, but at its most portable. This mind map established the groundwork for future designs.

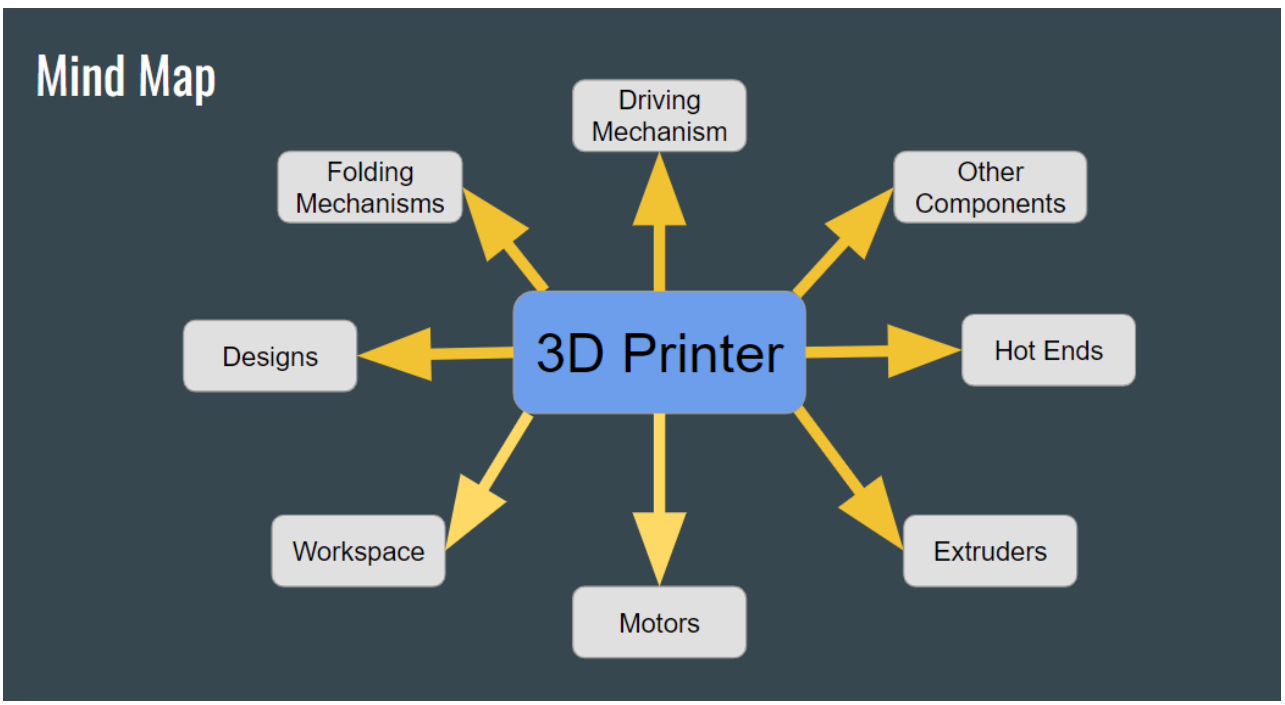

Figure 11. Mind Map

The mind map is divided into eight sections, each of which summarize the most valuable research concepts found from those sections. Figures 12-19 detail the various components that could be integrated into each section of the printer, complete with links to purchase destinations for specific parts.

4.1.1 Driving mechanism

The driving mechanism of the 3d printer (Figure 12) has three potential avenues of production: a ball screw, a conveyor belt and a lead, of which has 3 subsections for its various lengths.

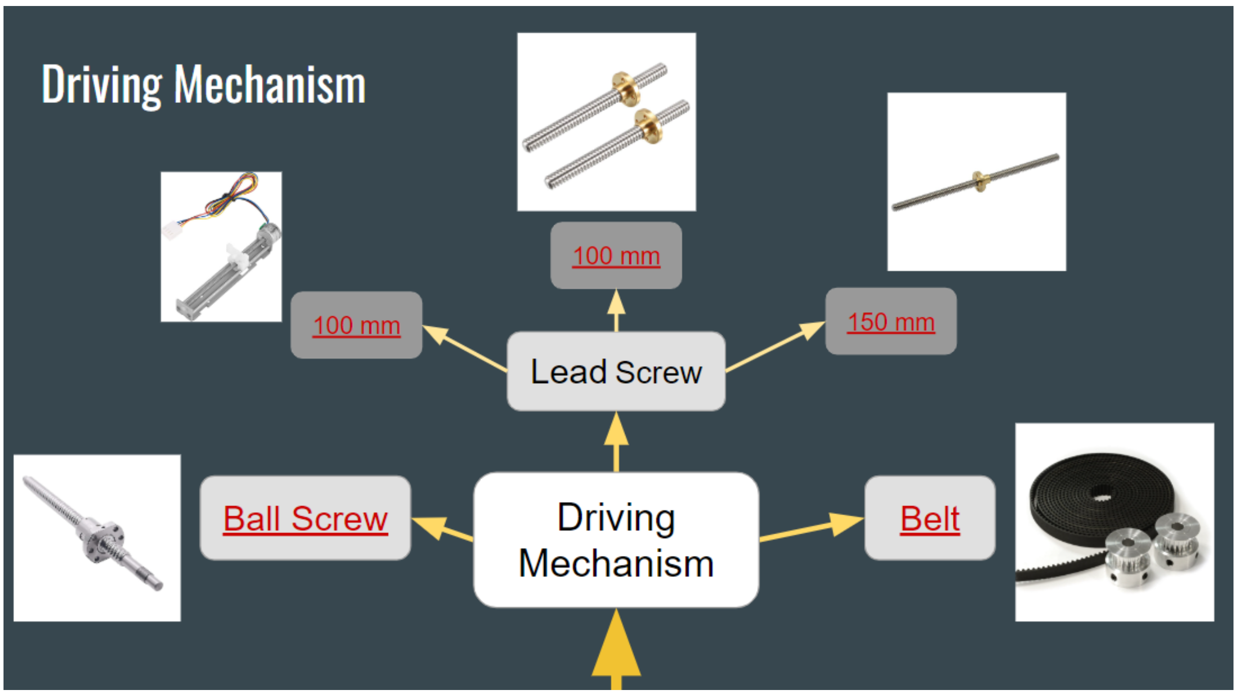

Figure 12. Mind Map: Driving Mechanism

4.1.2 Folding mechanism

Research into the folding mechanism of our 3d printer yielded three subsections of pivoting, collapsing and twisting. Different hinges, brackets and telescoping mechanisms were explored in this section.

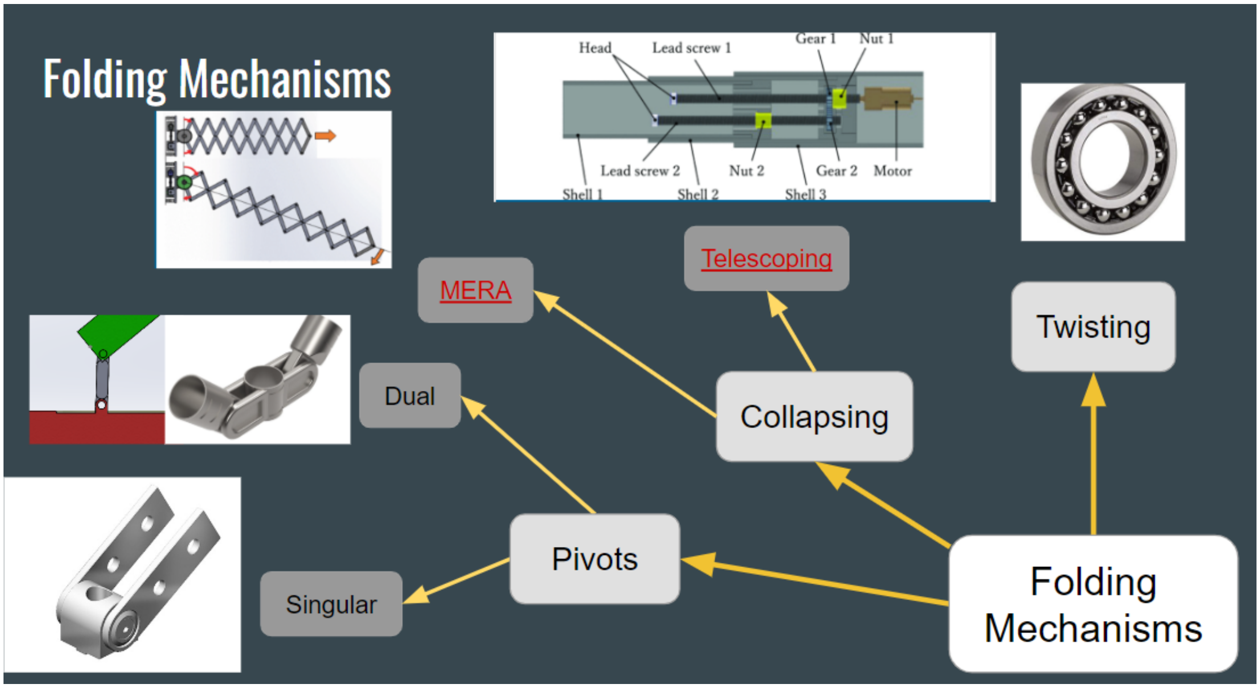

Figure 13. Mind Map: Folding Mechanism

4.1.3 Design

The design section of the mind map includes four subsections: polar, cartesian, delta and special, each of those containing examples of existing printers in the real world. The designs displayed drew inspiration from unique concepts found while researching and helped us gain valuable insight on which design concepts worked the best.

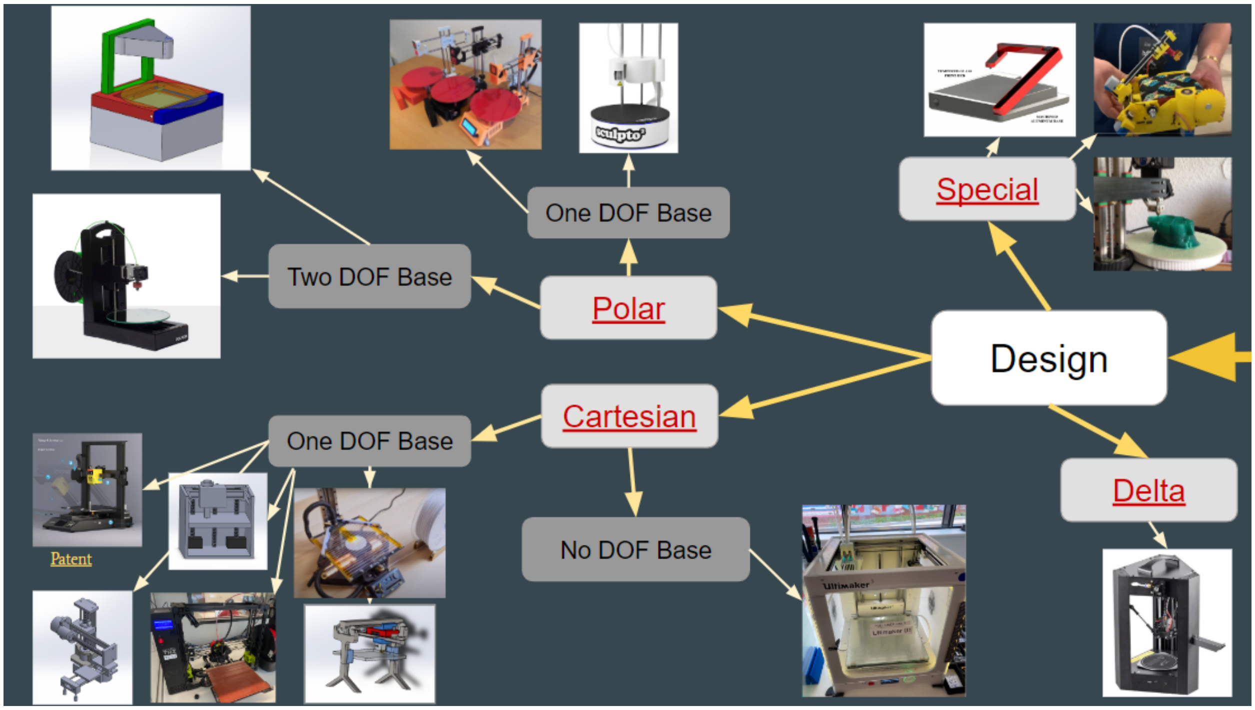

Figure 14. Mind Map: Design

4.1.4 Workspaces

The workspaces were limited to four subsections: cartesian, polar, spherical and delta, (Figure 15) however neither the spherical nor delta workspaces were plausible for designing a printer at the scale the team was looking for, thus polar and cartesian workspaces were more thoroughly looked into.

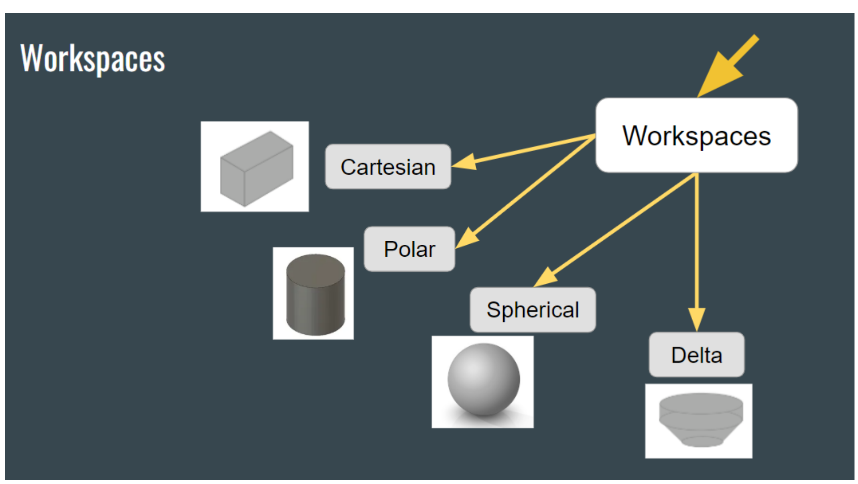

Figure 15. Mind Map: Workspaces

4.1.5 Motors

The motors section of the mind map was divided into three subsections: AC, DC, and special motors, of which is typically some combination of the two. Upon researching commercial 3d printing, the team found use for servo and CD-drive motors in addition to the well-known stepper.

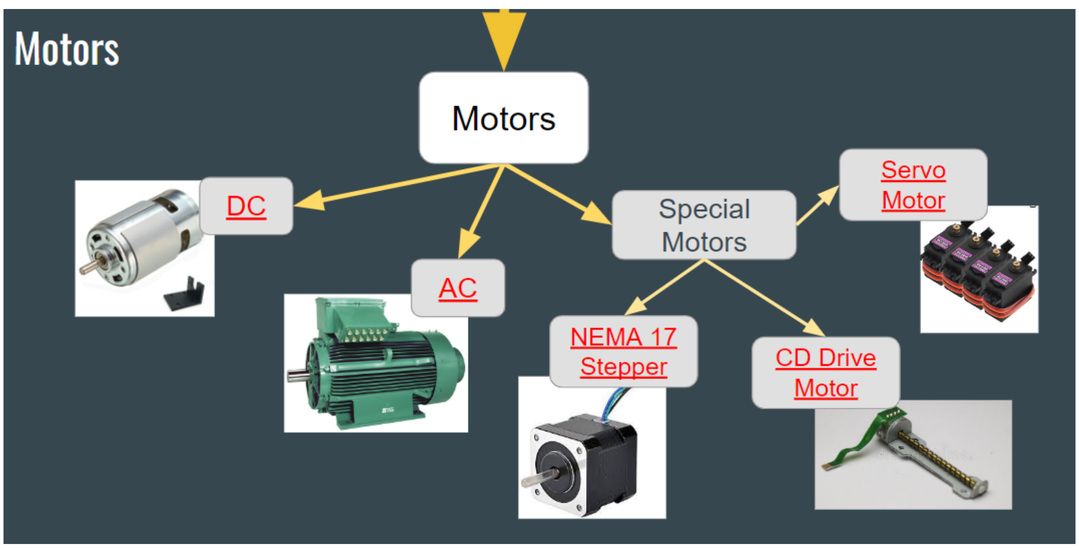

Figure 16. Mind Map: Motors

4.1.6 Extruders

The extruders section of the mind map details both single-geared and dual-geared drives of which can manifest in either the bowden or direct configuration. For the scale of our application, the team focused on a direct approach to save space.

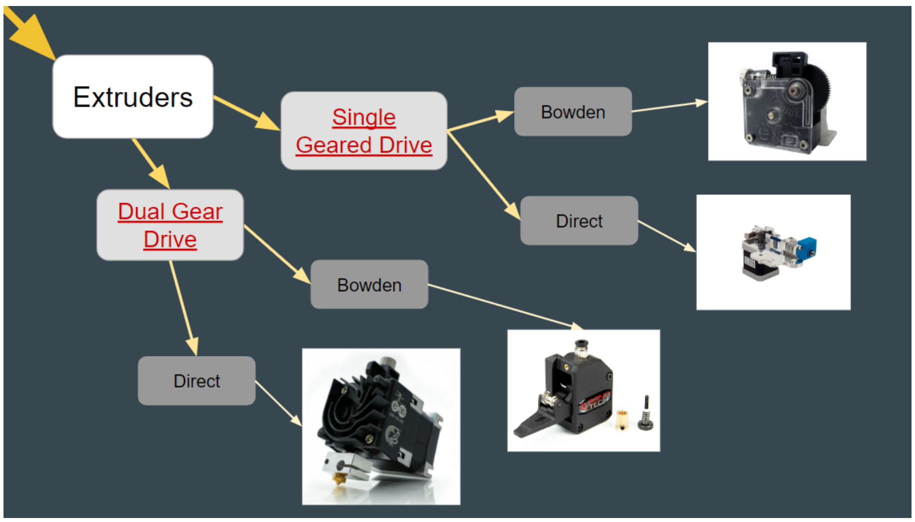

Figure 17. Mind Map: Extruders

4.1.7 Hot End

The hot end section shows with images, the different options for nozzles as well as the extruder and whether or not to use a fan. Keeping the printer's scale in mind, the team explored several of these options, dependent on size and weight.

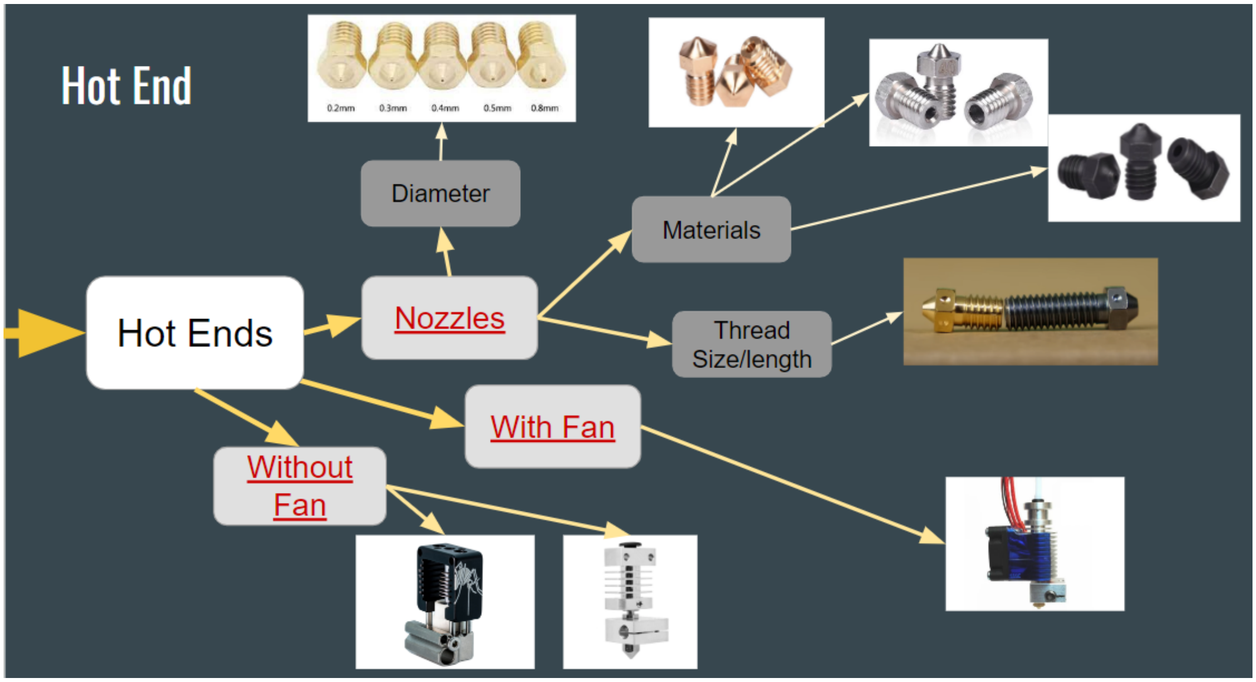

Figure 18. Mind Map: Hot Ends

4.1.8 Other Components

The other components that were added to the mind map include the electronics such as PCBs and limit switches, as well as the physical structure of the 3d printer, namely the walls and bed which will undergo manufacturing.

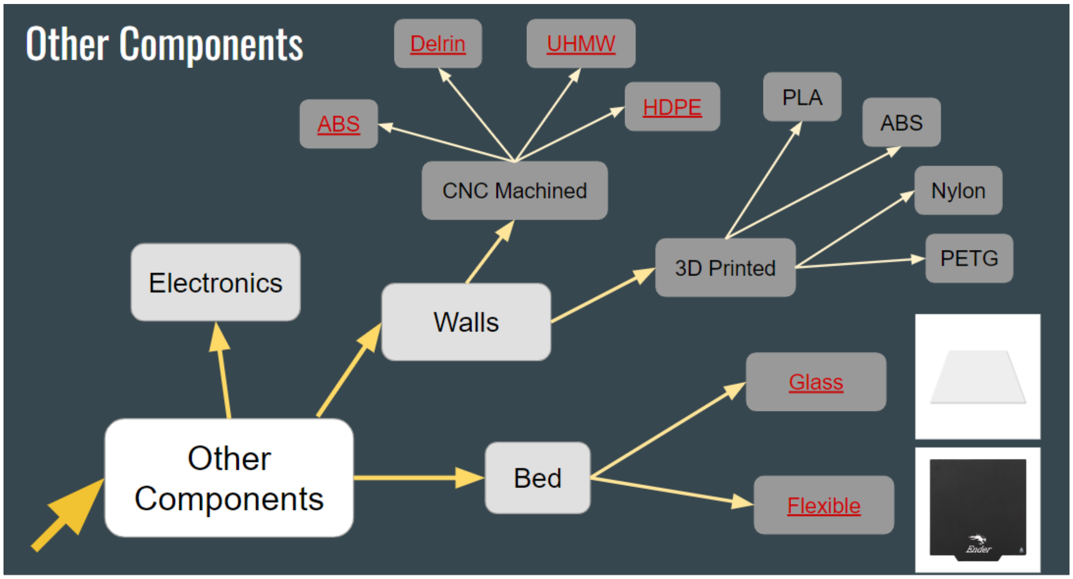

Figure 19. Mind Map: Other Components

4.2 Circle Sketches

Four circle sketches were made once completing the mind map. Each member started by sketching a rough design of a 3D printer using promising aspects of their research. Each sketch was then passed around to the next member to add a detail/suggestion, hence the name circle sketch.

4.2.1 Kevin's Circle Sketch

Kevin's original design intent was to have a Cartesian 3D printer, which uses a combination of a foldable print bed and a collapsible arm (Figure 20). Some of the group suggestions included: having two towers for Z-axis movement, tracks for the arms, standing and transport version, etc.

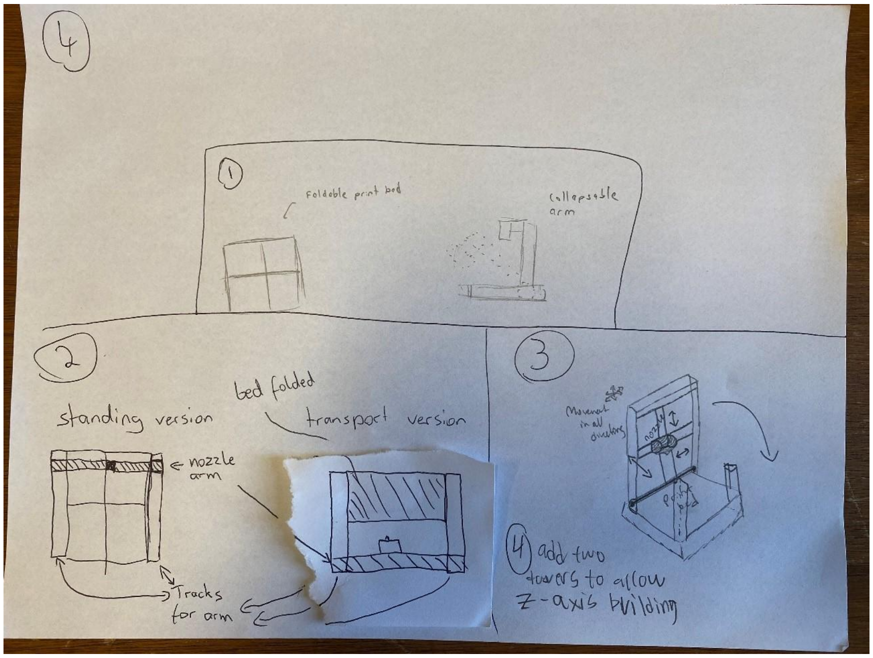

Figure 20. Kevin’s Circle Sketch

4.2.2 Tim’s Circle Sketch

Tim’s original design intent was to have a Cartesian design with a Z-axis that folds towards the bed (Figure 21). The suggestions include having the “flaps” underneath fold up to form a box, folding the z axis backwards, and adding magnetic tracks which the z axis would slide along.

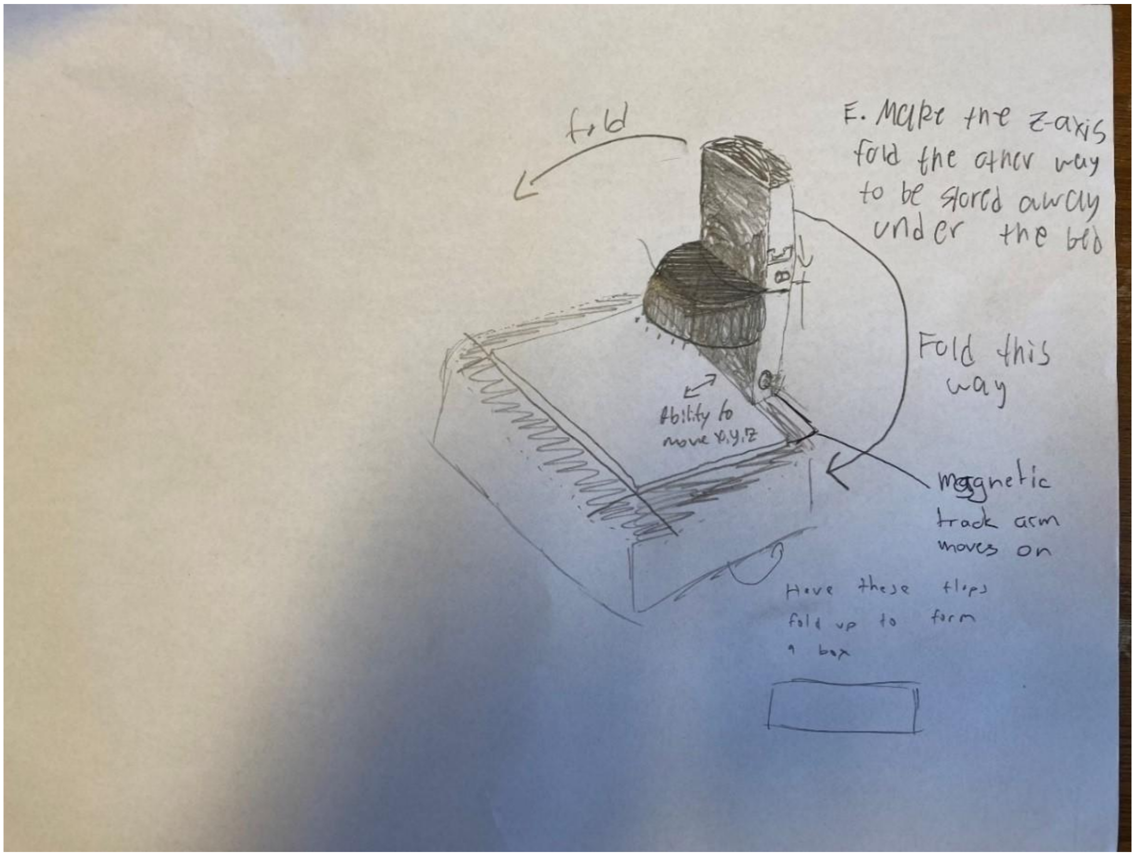

Figure 21. Tim's Circle Sketch

4.2.3 Esteban's Circle Sketch

Esteban's original design intent was to have a Cartesian 3D printer and something like a 'scorpions' tail' for the Z-axis (Figure 22). The suggestions made were to have the 'tail' fold down into the bed, using multiple v-shaped parts for the z axis that slide into each other, and a telescoping mechanism for the z axis.

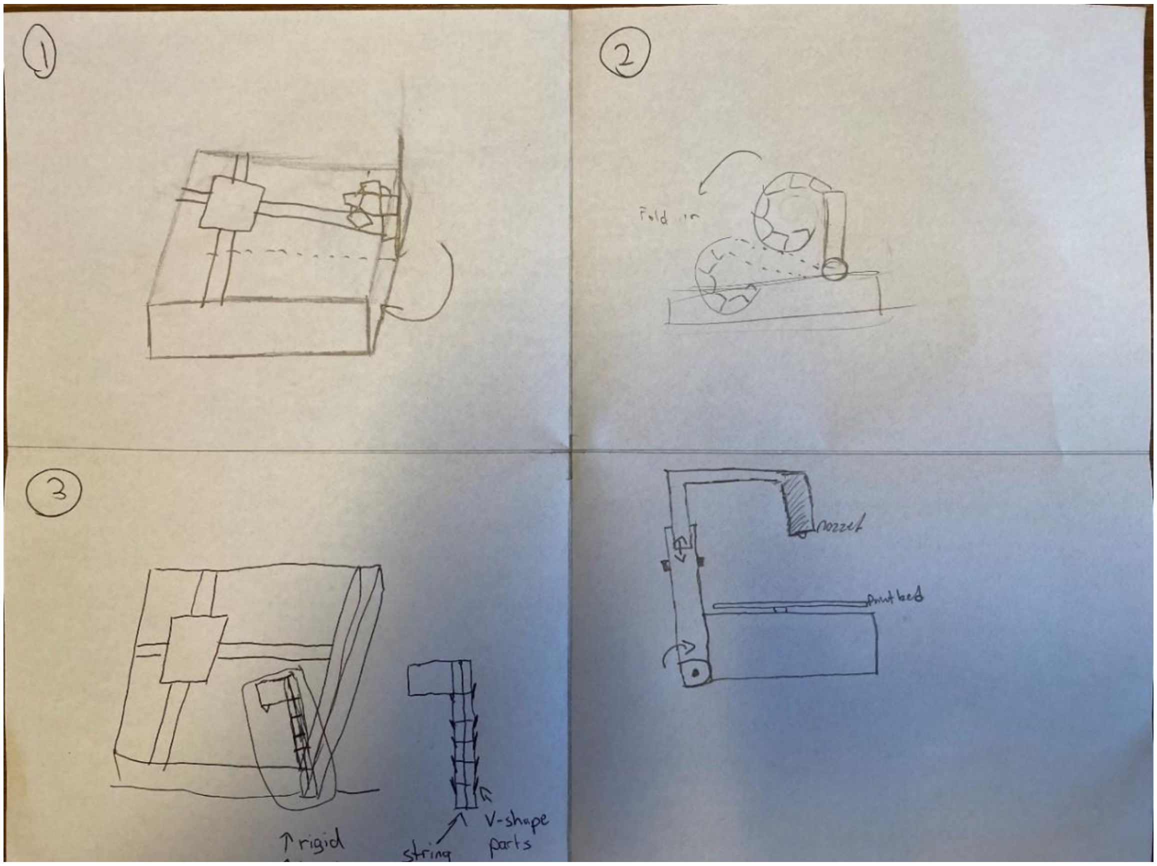

Figure 22. Esteban's Circle Sketch

4.2.4 Niklas's Circle Sketch

Niklas's original design intent was to have a polar design with a Z-axis that extended upwards using a pneumatic system (Figure 23). The suggestions include a collapsible arm using a pivot, and a E-z up design.

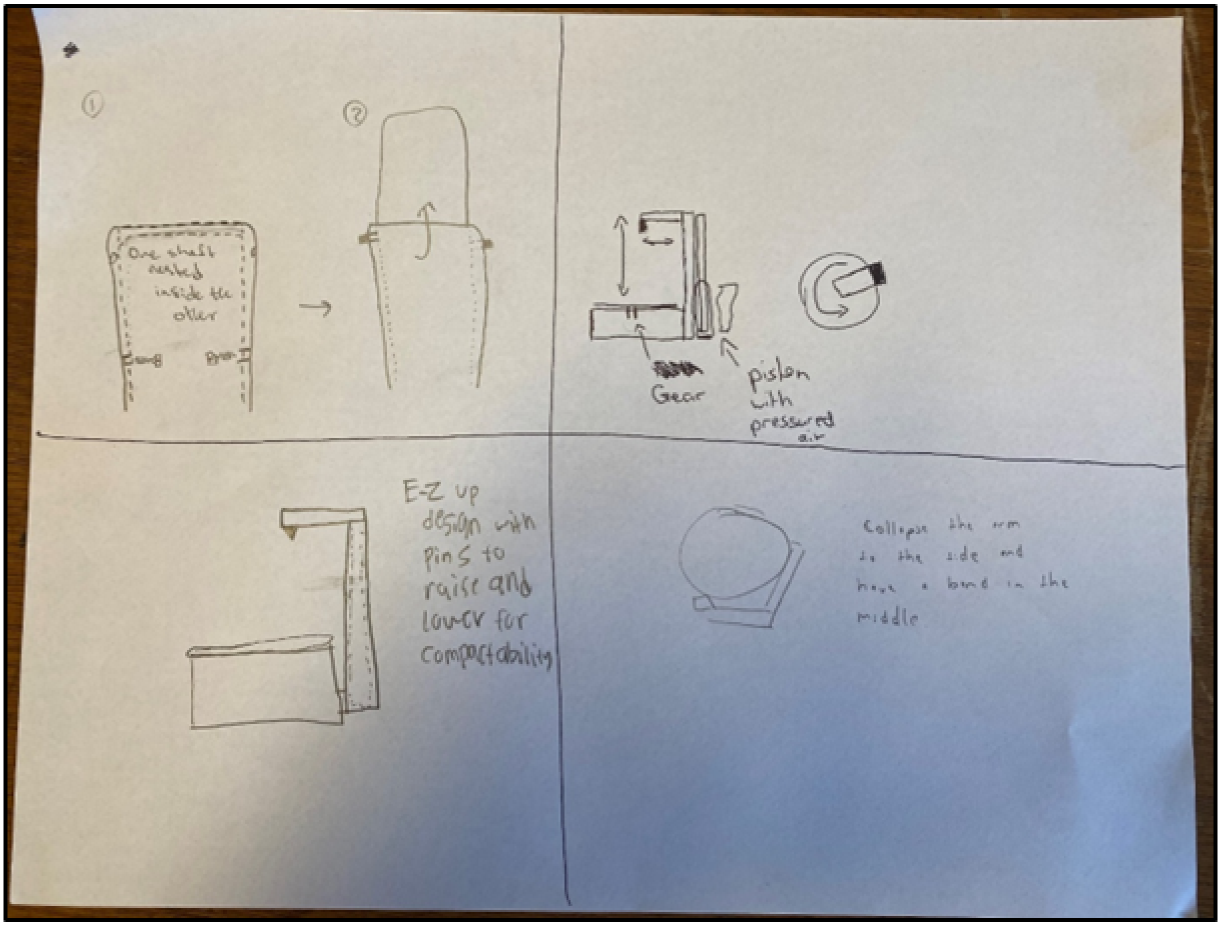

Figure 23. Niklas's Circle Sketch

5.0 Initial Design Ideas

Once the circle sketches were completed, the team set out to each design a proof of concept. Each group member came up with a unique design to promote creativity and showcase different approaches to the main challenges in the design.

5.1 Kevin's Initial Design 1

5.1.1 Design Iteration 1

Kevin's first design iteration was the implementation of a swivel and a slide to fold the Z-axis down (Figures 24 and 25). This design's focus was to create a way to have the 3D printer as flat as possible to fit nicely into a student's bag.

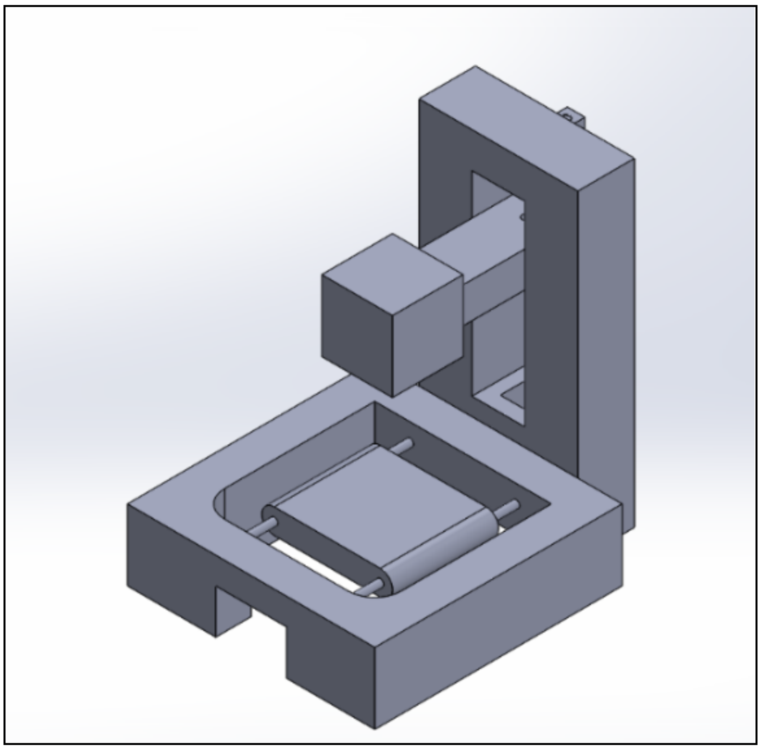

Figure 24. Design Iteration 1 Upright

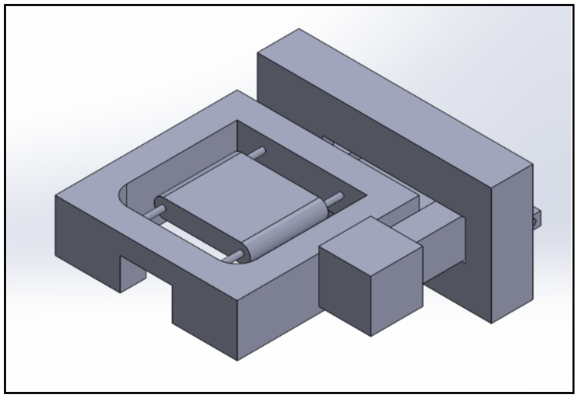

Figure 25. Design Iteration 1 Folded

5.1.1 Design Iteration 2

Kevin's second design iteration was having the Z-axis fold towards the bed and have the bed fold up (Figures 26 and 27). This design also added more detail to the design to see how it would look.

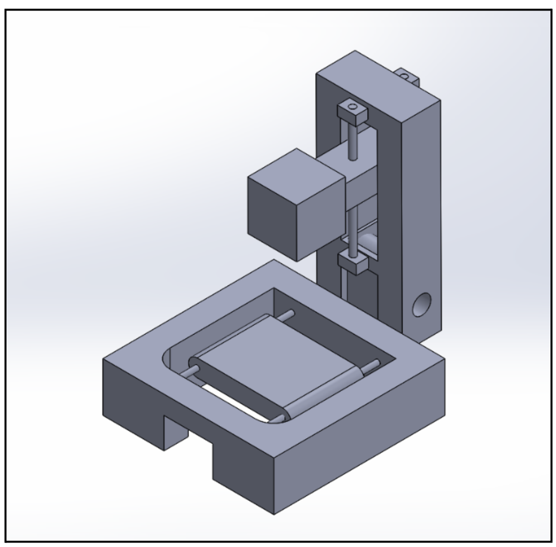

Figure 26. Design Iteration 2 Upright

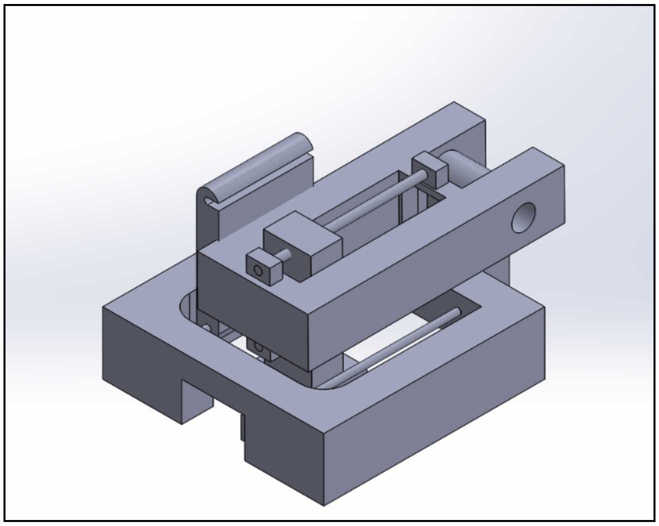

Figure 27. Design Iteration 2 Folded

5.1.1 Design Iteration 3

For the third design, Kevin decided to go for a cantilever design (Figures 28 and 29). By doing this, the hot end could move in both the X and Z-axis. To fold this design, the 'cantilever' section would rotate up and then the bed would fold up as shown in figure 29.

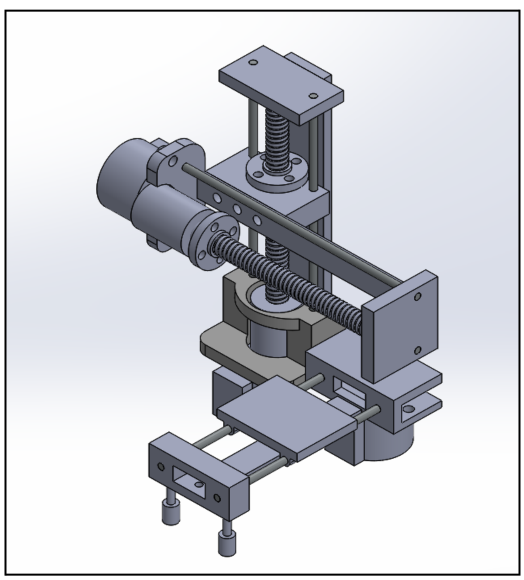

Figure 28. Design Iteration 3 Upright

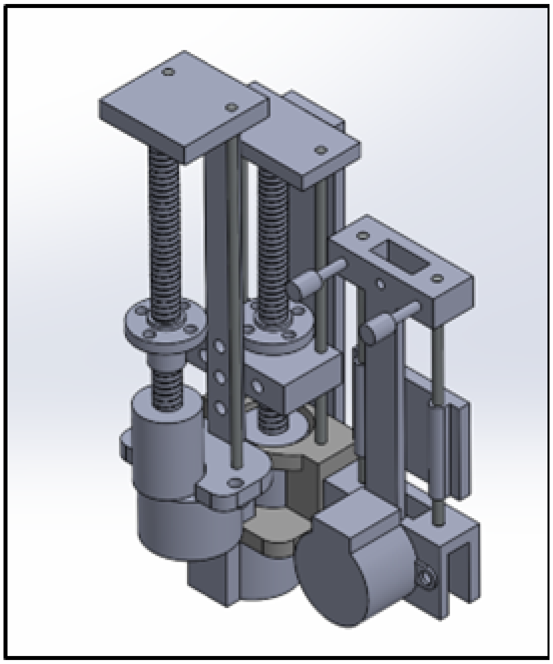

Figure 29. Design Iteration 3 Folded

As shown, a few design iterations were made during this process. The ones shown were the ones believed to be the most notable. As you can tell, design three was the most complex with the intent of it being Kevin's final design consideration (more on this in the next chapter).

5.2 Niklas' Initial Design

5.2.1 Design Iteration 1

Initial Design 2 was designed around an expanding base design shown in figure 30 below. The design works by utilizing one stationary part illustrated in red and one mobile part illustrated in blue. The blue piece can freely slide in and out the red piece increasing its footprint. The gained space can then be used by the bed illustrated in yellow to slide along the 4 rails in the center of the base. One bigger threaded rod was present in the middle of the base which was later removed.

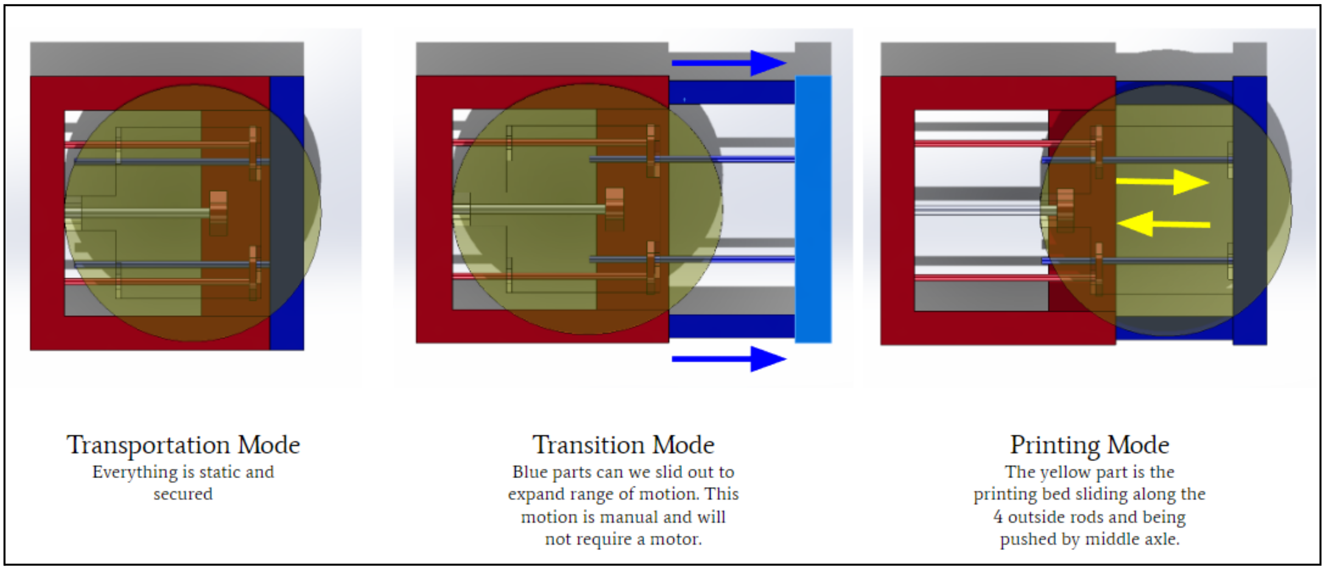

Figure 30. Base Design for Design Niklas' Initial Design

The first complete design with this base is shown in figure 31 and 32. The z axis in this design would move up and down using threaded rods which are covered by the green part. At its lowest position the printer would be in "transport mode". The overall size of this design was 160 x 160 x 120 mm, which fit our design requirements, and with a printing volume of 1.22 Liters, the printing volume to overall volume was 1:2.5. This design's main disadvantages were having a cuboid shape which did not fit the team's expectations.

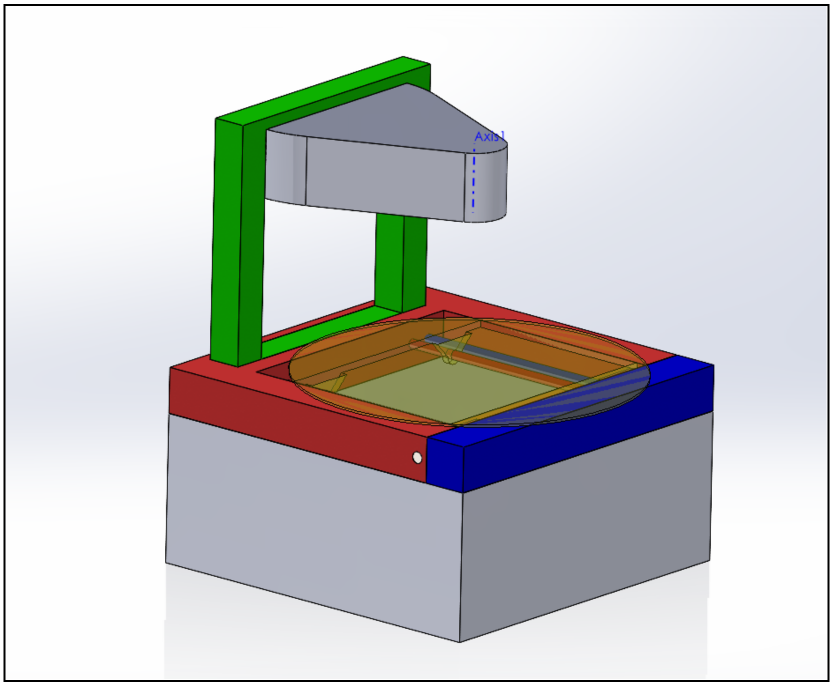

Figure 31. Design Iteration 1 Expanded

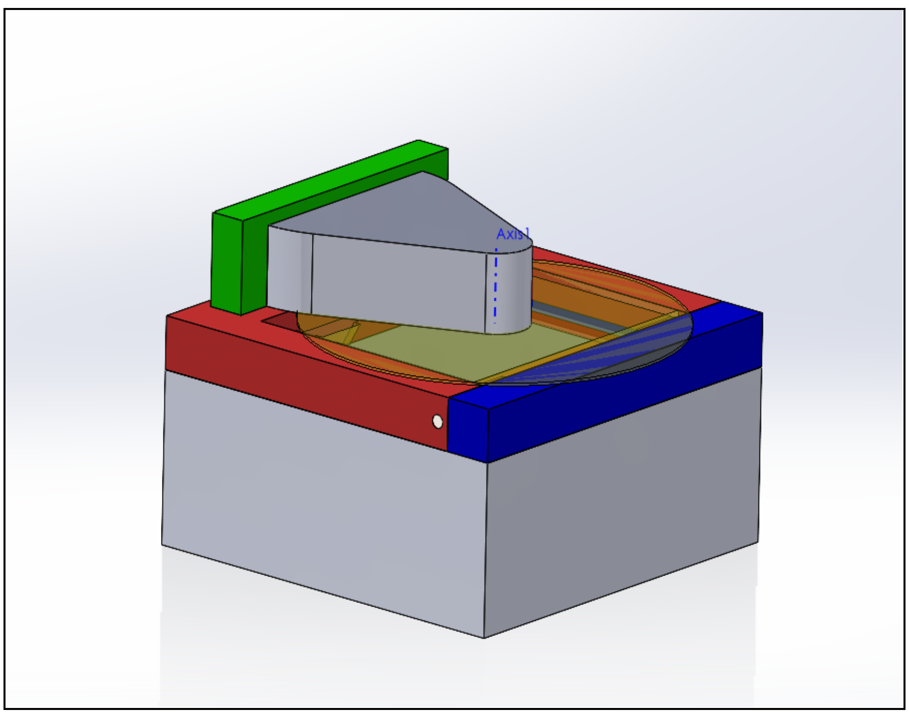

Figure 32. Design Iteration 1 Collapsed

5.2.2 Design Iteration 2

The second iteration of Niklas' design incorporated a pivot mechanism which would fold the nozzle and z axis over the printing bed as seen in figure 33. The pivot uses two separate pivot joints to fold past the edge of the bed. In the upright position, the arm of the printer, illustrated in green, uses 3 separate centering rods or pins to stay rigid. The disadvantages of this design are the need to add and remove pins when setting the printer up the print. Additionally, the pivot only added to the overall volume of the printer and did not expand on the printing volume.

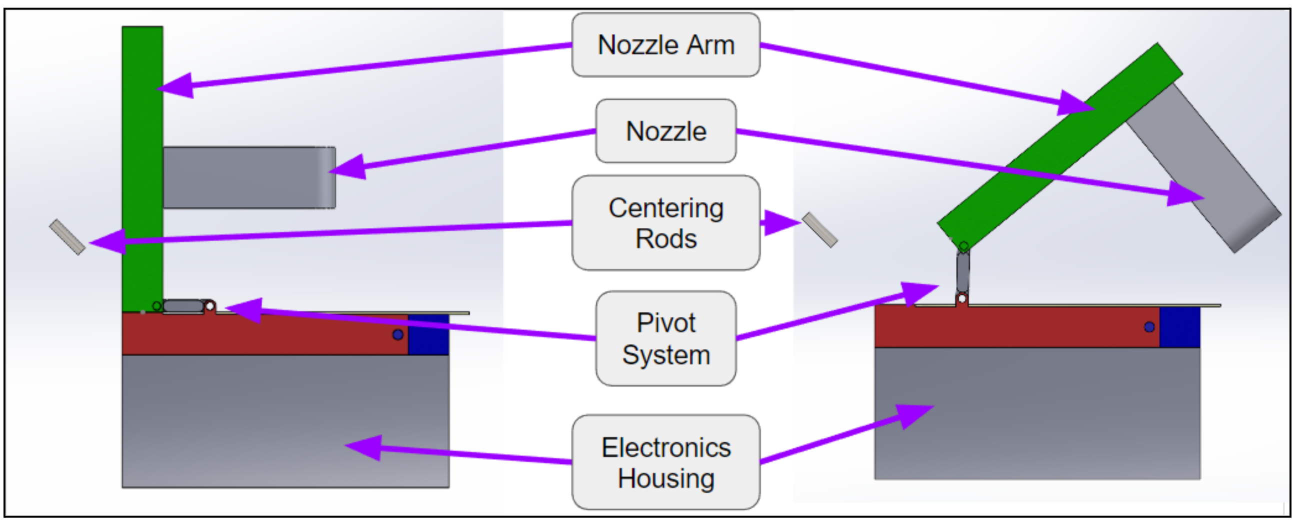

Figure 33. Design Iteration 2

5.3 Tim's Initial Design

5.3.1 Design Iteration 1

Tim's initial design consideration is one of a cartesian-style printer, which uses a belt system to drive linear translation in the x, y and z. The main proponent of movement in this design is the XY gantry system shown (Figure 34) and a series of motor-driven linear sleds that move along rails. This idea drew inspiration from the aforementioned Positron 3D printer for its sleek design as well as its unique printing style.

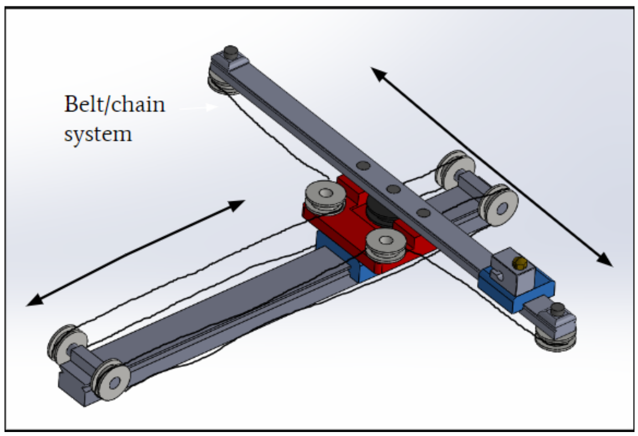

Figure 34: XY Gantry Design (Tim)

5.3.2 Design Iteration 2

In addition to the XY gantry, a 6 x 6" glass bed which can swivel upright into a flat position was incorporated into the design, adding to the sleek look. Some disadvantages of this printer however, include its fragility in the printing position as well as its reliance on tensioned belts, which are prone to loosening during printing. Figure 35 below demonstrates the foldability of the printer bed.

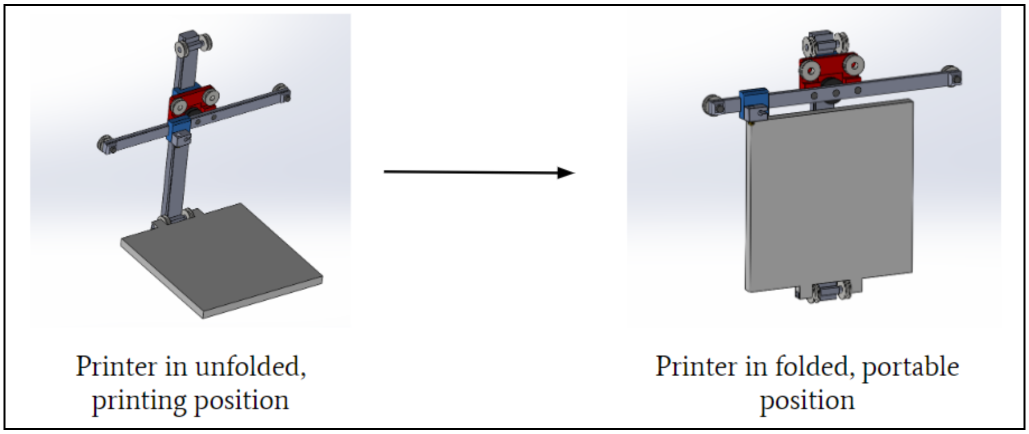

Figure 35: Design Iteration 2 (Tim)

5.4 Esteban's Initial Design

5.4.1 Design Iteration 1

Esteban's Initial design made use of a rotating z-axis tower that would fold over into the bed to occupy less space in the collapsed position. The tower would lock into place via pins so it would not move or wiggle when in the active position. The pins could then be removed allowing the tower to spin about the z-axis so the nozzle is facing away from the bed as seen in figure 36. The piece on the back of the printer would allow the entire tower to pull away from the bed and give the nozzle enough space to fold over as shown in Figure 38.

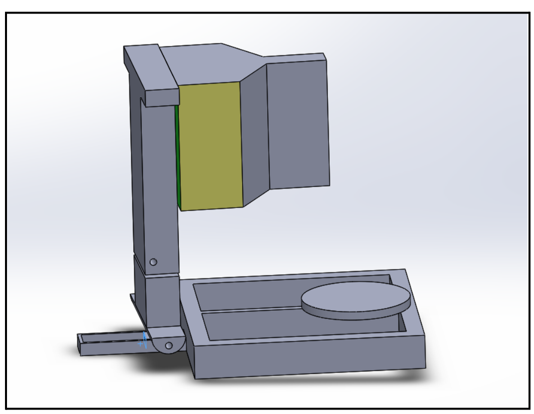

Figure 36: Design Iteration 1

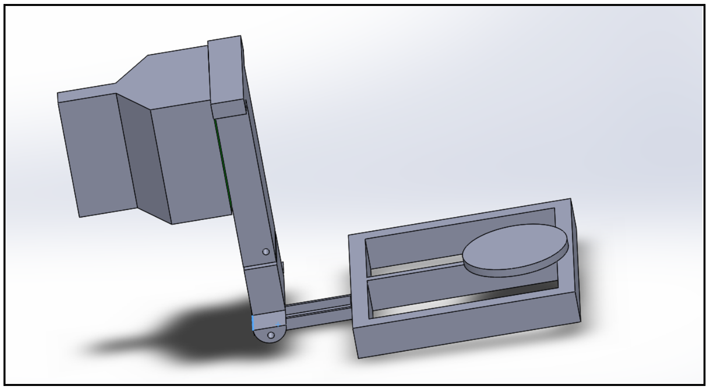

Figure 37: Rotated Away

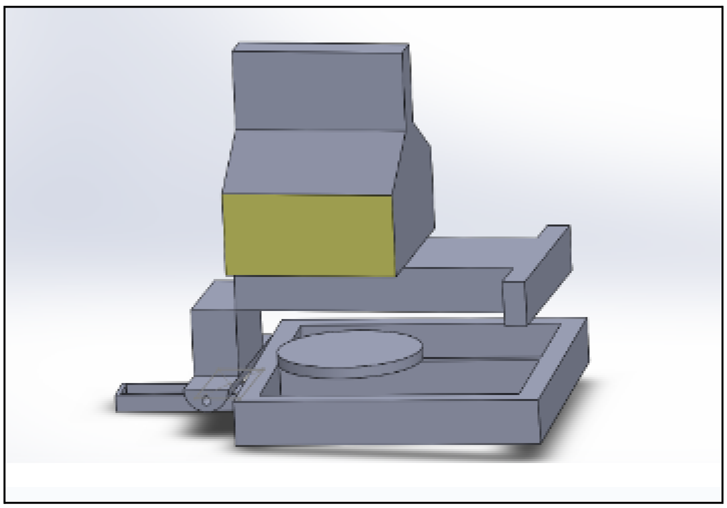

Figure 38: Collapsed Position

5.4.2 Design Iteration 2

Esteban's Second design followed similar printers that were available on the general market. The main premise of this design is the bed that moves up and down rather than the nozzle. The nozzle would move with the hot end along a rail moved by wheels on an x-bar. The focus of this design was observing how minimal a printer could get while remaining space efficient. The CAD model for this iteration can be seen in Figure 39.

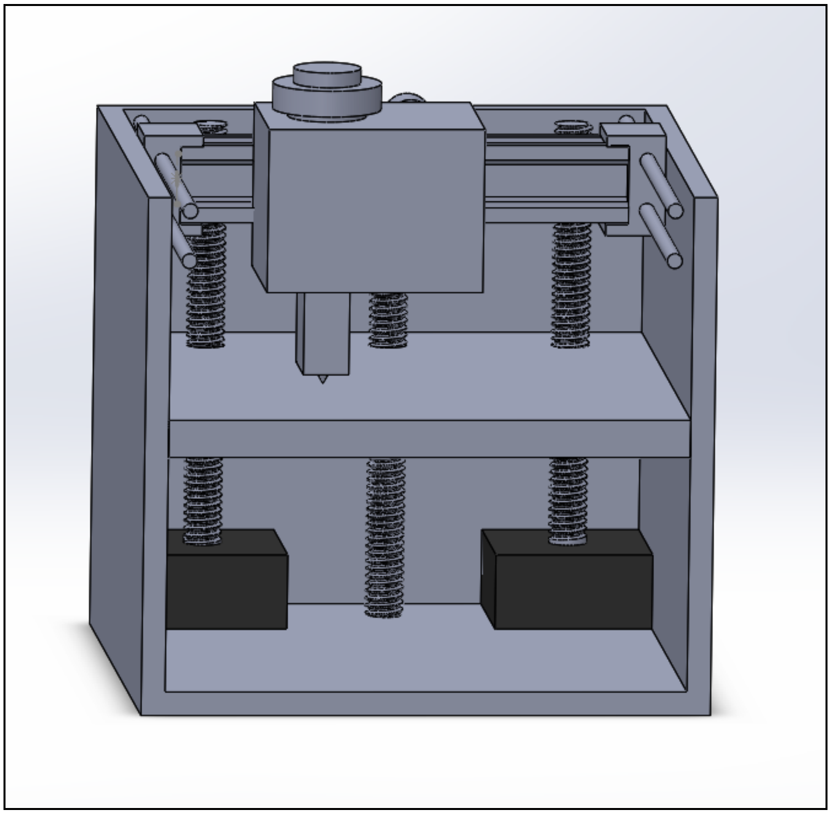

Figure 39: Esteban's Second Iteration

5.4.3 Design Iteration 3

Esteban's third iteration was a collaborative effort with Kevin where the desirable aspects of both teammates' previous iterations were combined to make a better design. A very slim flat design was the approach to this design making the entire printer very thin. The active position would have a kickstand for stability shown in the bottom left corner of figure 40. The compressive capabilities of this design was mainly found in the bed. The idea was to have the bed slide away from the nozzle and fold onto itself shown in figure 41 creating an extremely flat inactive position.

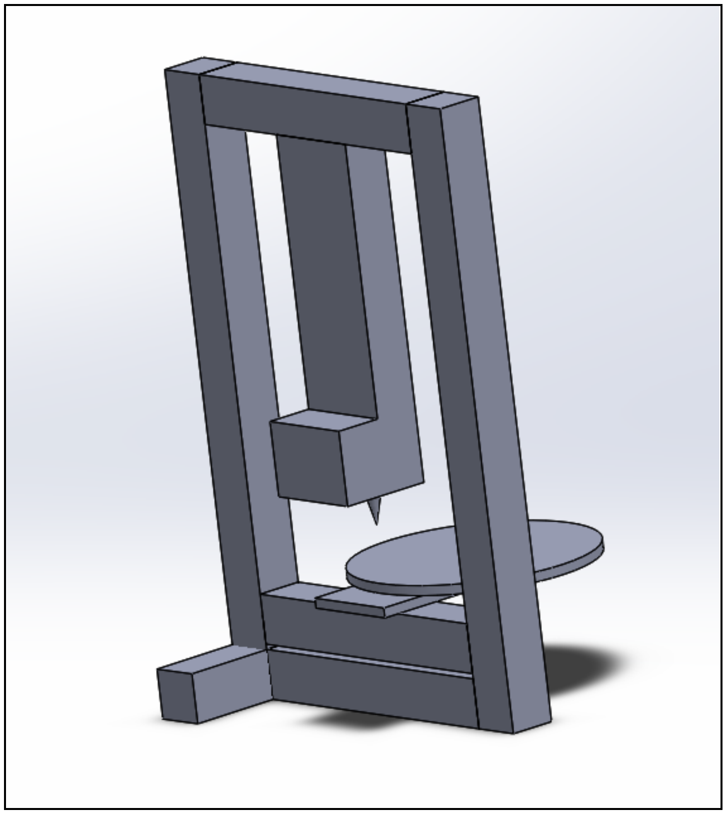

Figure 40: Esteban’s Third Iteration

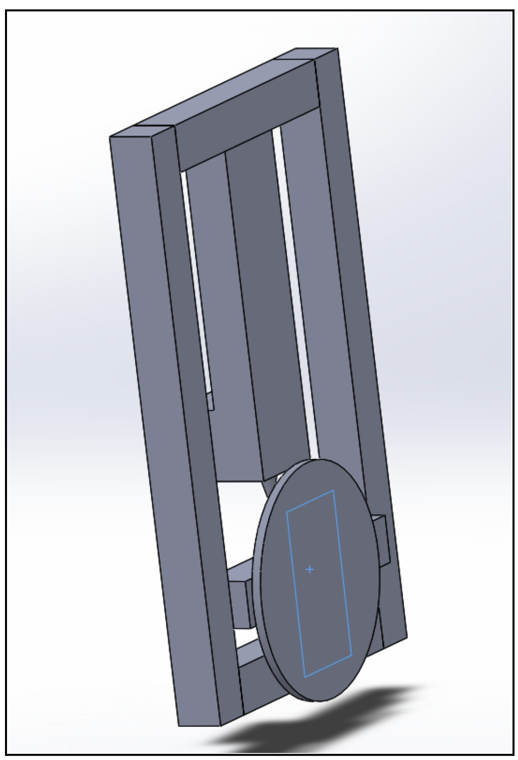

Figure 41: Folded Inactive Position

6.0 Final Design Considerations

In this section, the different final design considerations will be talked about and how we limited it down to one idea. The design that we decided to choose is what we will work on for the remainder of the year.

6.1 Design Consideration 1 (Tim):

Tim's final design consideration showcases a Cartesian 3D printer that has the print bed moving along the Z-axis, while the nozzle moving in both the X and Y-axis (Figure 42). In addition, the Y-shaped legs would fold at the midsection to create a more compact design during transportation.

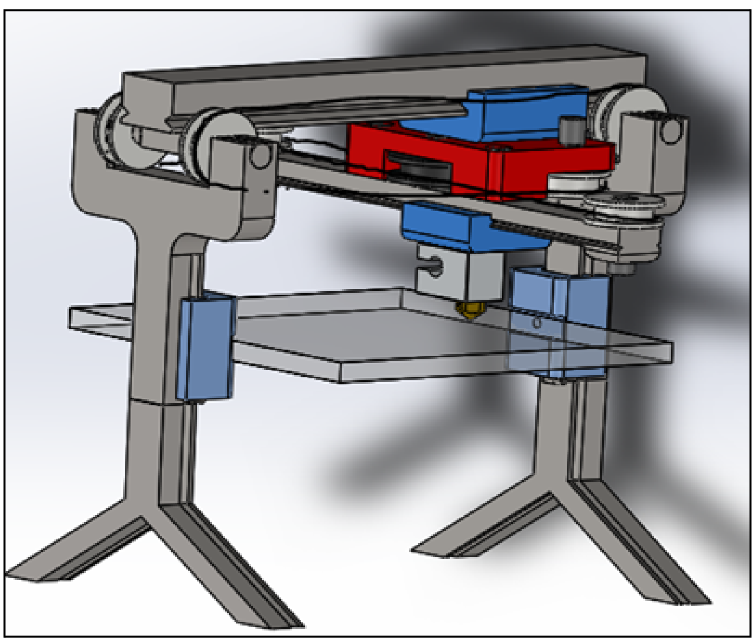

Figure 42. Design Consideration 1 (Tim)

6.2 Design Consideration 2 (Kevin):

Team member discussion led us to putting the Z-axis on a swivel and would make the design flatter when transporting (Figure 43). If this design was chosen, that would be one of the areas to be worked on right away.

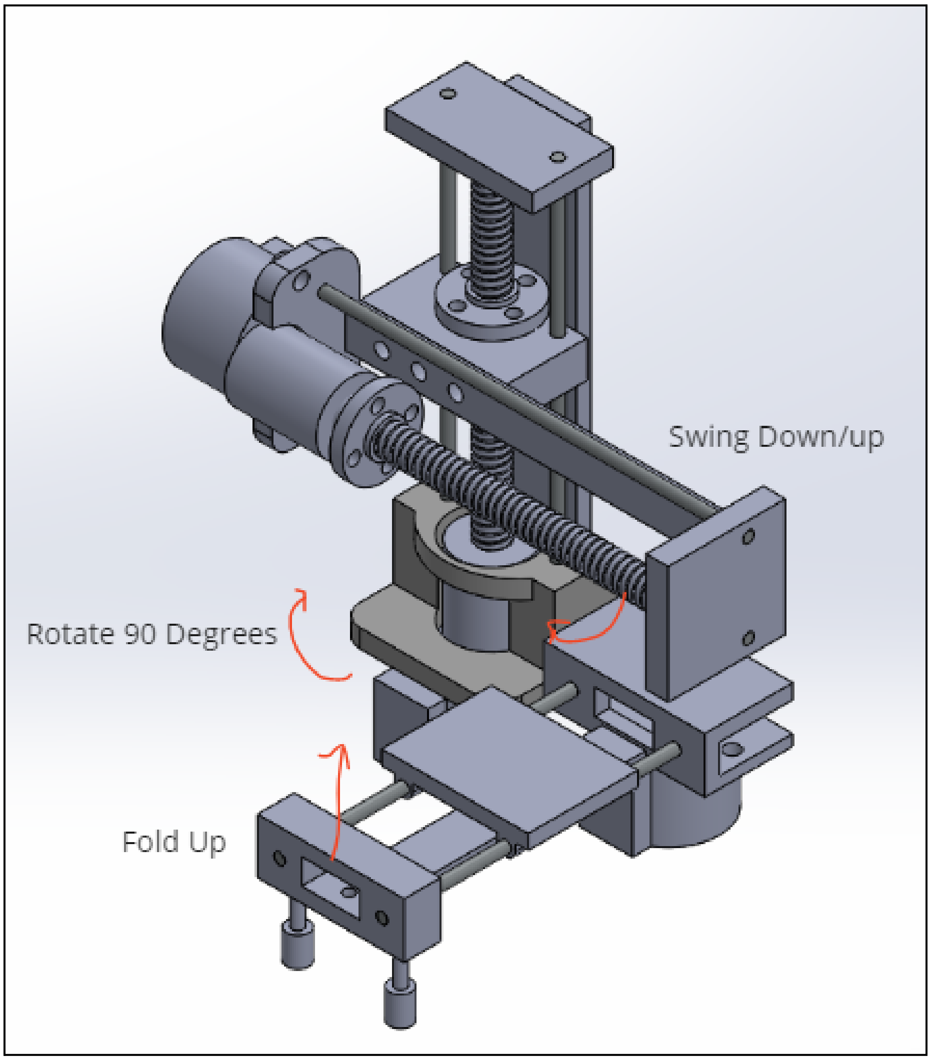

Figure 43. Design Consideration 2 (Kevin)

6.4 Design Consideration 3 (Esteban):

Esteban's final design consideration shows a polar 3D printer with the print bed being able to slide out and fold down (Figure 44). The sliding function would also handle the X-axis movement, and the hot end would move along the side rails (Z-axis).

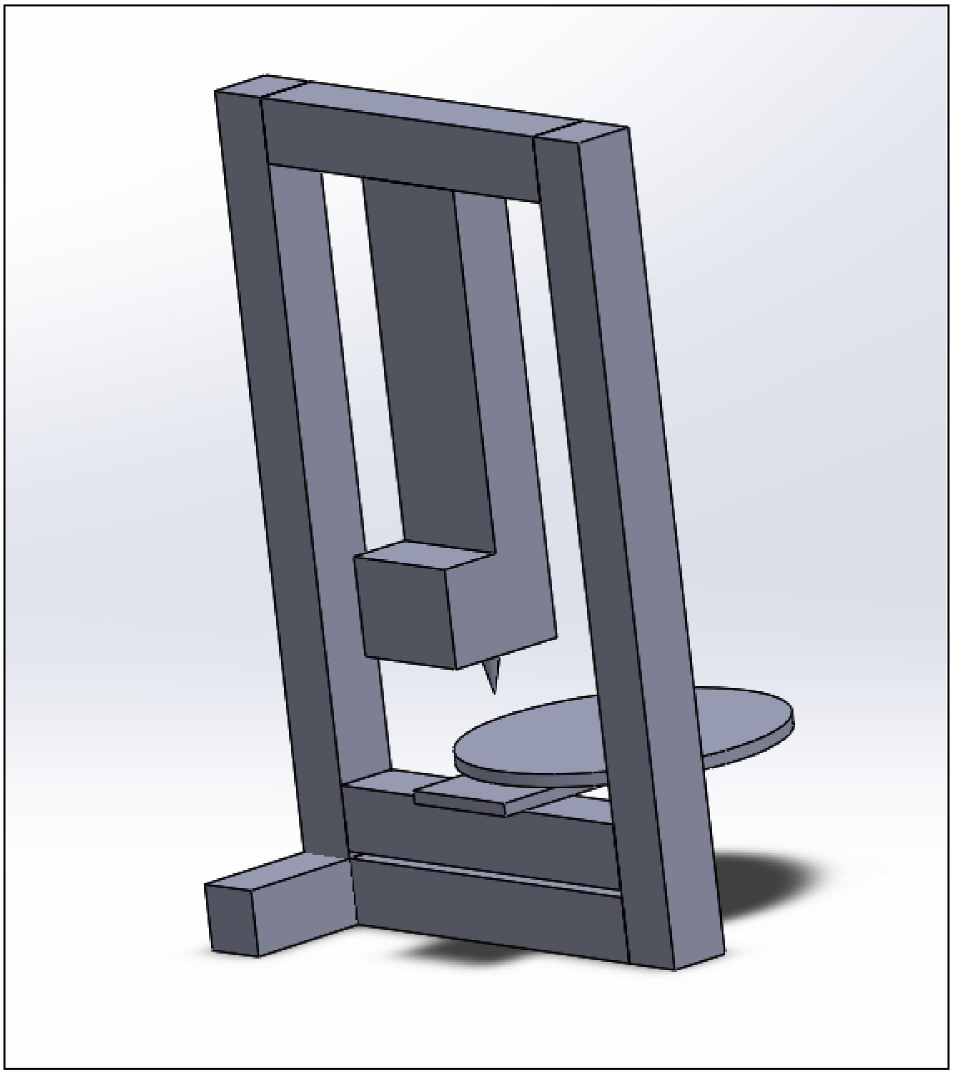

Figure 44. Design Consideration 3 (Esteban)

6.5 Design Consideration 4 (Niklas):

Niklas' final design uses a polar coordinate system with a folding arm and expanding base (Figure 45). The arm had one degree of freedom along the z axis. The bed has two degrees of freedom along the x axis as well as being free to rotate. The design's advantages are a thin design that can easily fit into a backpack. This increases its portability drastically compared to other more cube shaped designs. This design also has a designated space for electronics unlike other designs.

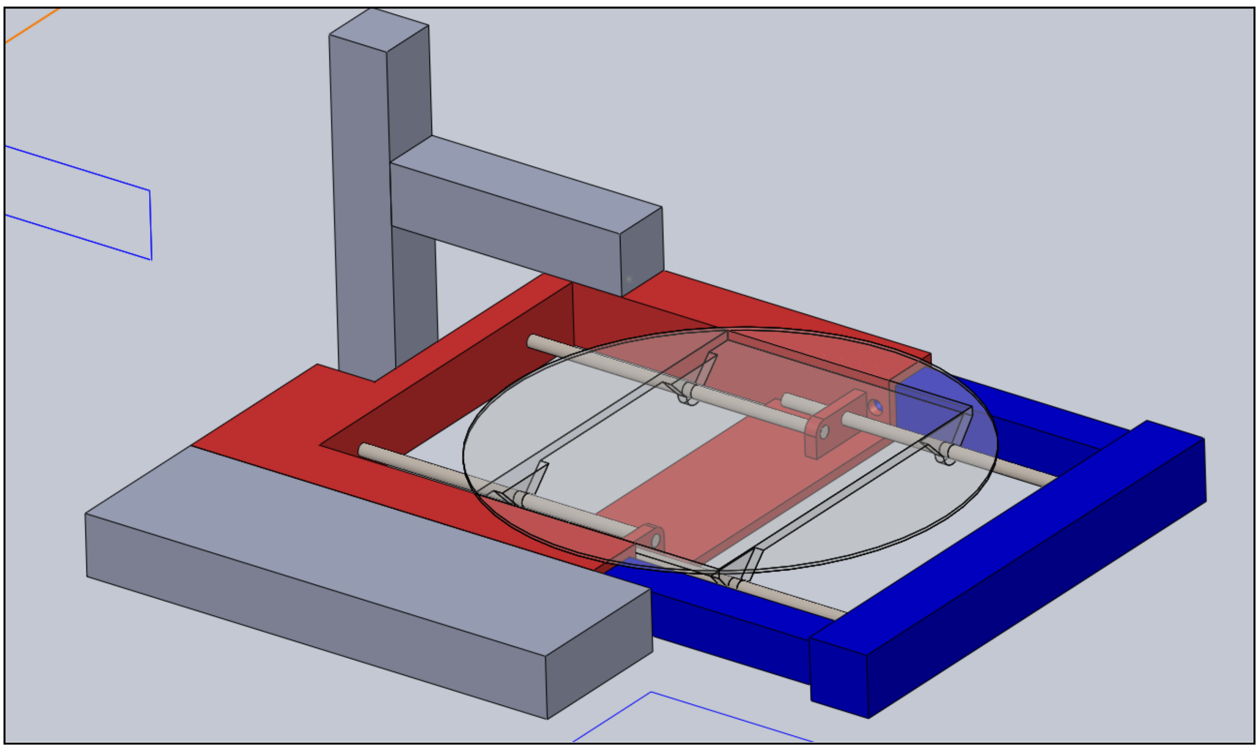

Figure 45. Design Consideration 4 (Niklas)

Pugh Charts are helpful tables used to organize and prioritize certain variables. The variables being considered for the final design of the printer are plotted against other variables and the team determines which takes precedence over the other. Each column in the table is compared to the variable on the corresponding row. If the column is deemed more important than the row the cell is given a value of 1. If the row variable is deemed more important than the column it is given a value of –1. If the variables in the column and row are deemed equal the cell is given a value of 0. After each cell has been analyzed the columns are summed up at the bottom. After the Pugh chart was completed the team found that portability should be the main focus of the printer when considering the final design. The safety and reliability of the printer came as a close second. Aesthetics and cost were considered, however, were determined not a priority for the final design.

	Portability	Size	Weight	Print Size	Cost	Aesthetics	Safety/Reliability
Portability	-	-1	-1	-1	-1	-1	0
Size	1	-	-1	1	-1	-1	0
Weight	1	1	-	1	-1	-1	1
Print Size	1	-1	-1	-	-1	-1	1
Cost	1	1	1	1	-	-1	1
Aesthetics	1	1	1	1	1	-	1
Safety/Reliability	0	0	-1	-1	-1	-1	-
Total	5	1	-2	2	-4	-6	4

Figure 46. Pugh Chart

Pugh Matrix charts are a similar way of comparing the 4 design considerations shown above. Concepts 1,2,3 and 4 represent figures 42-45 respectively. Concept 1 serves as a base design that the other 3 will be compared to. Starting from the top of a column the selected concept will be directly compared to Concept 1. If the concept has better aspects of the variable when compared to the base design it will be given a +, a – if it is worse, or a 0 if the comparison is equal or unknown. The plusses will add a value of 1 while the minuses subtract 1 from the final score. The final score showed concept 4 as having the most desirable aspects in all categories. Concept 3 had some appealing aspects, but not enough to continue forward with it as the final design. Moving forward the final design will be heavily influenced by Concept 4 based on the Pugh matrix.

	Concept 1	Concept 2	Concept 3	Concept 4
Portability	0	+	+	+
Size	0	+	+	+
Print Size	0	-	-	+
Ease of use	0	-	+	+
Cost	0	0	0	0
Complexity	0	+	+	+
Aesthetics	0	-	-	+
Safety/Reliability	0	0	+	+
Sum of +	0	3	5	7
Sum of -	0	3	2	0
Sum of 0	11	2	1	1
Net Score	0	0	3	7
Rank	3	3	2	1

Figure 47. Pugh Matrix

<u>7.0 Prototype</u>

Now, the process of designing the prototype will be discussed, such as the CAD modeling and manufacturing to the standalone model. All important features of our design will be documented chronologically in the sections that follow.

7.1 Base

7.1.1 Base Assembly Iterations

Once the team decided on using the fourth design the base of the existing design was flushed out. Most notably, the threaded rod in the center of the base was removed. Now in order to move the bed in the x axis, a threaded rod replaced one of the simple rods attached to the static base. Additionally, a motor was attached to the threaded rod and slotted on the static base. Some minor changes included adding a fillet to the sliding base corners that interface with the static base, as well as minimizing the material of the static base which holds the centering rods.

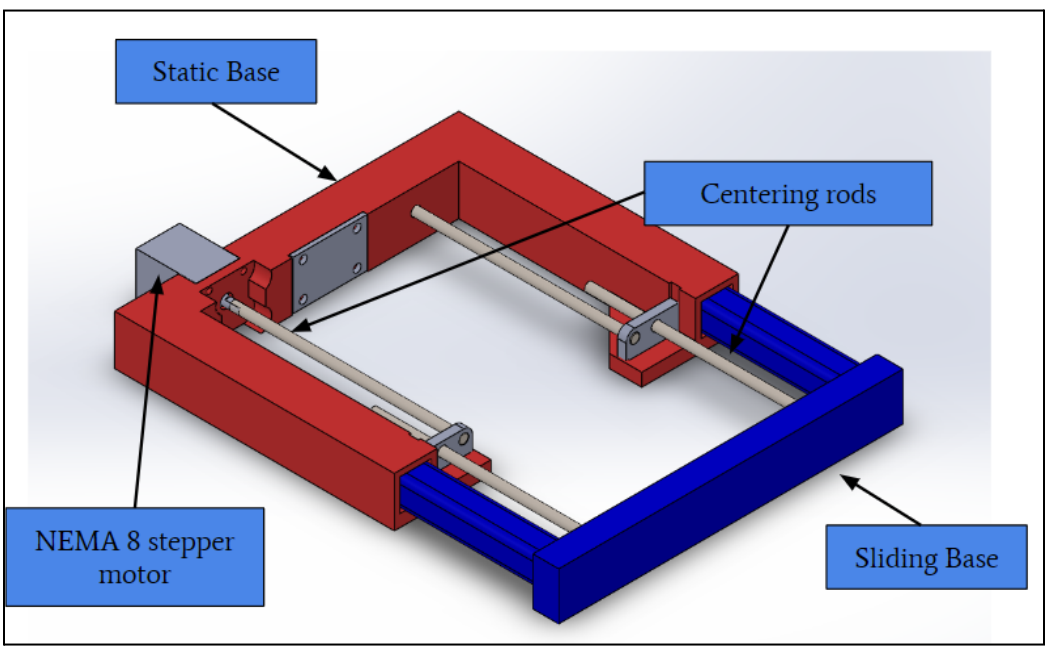

Figure 48: Updated base assembly

Throughout the term the base stayed relatively untouched and only experienced one change. This change introduced a locking mechanism to the base that holds the sliding base in place at either the expanded level or collapsed level. This mechanism works similar to a ball detent by having two holes in the static base and one hole in the sliding base. A cylinder shaped piece is then inserted into the sliding base with a spring underneath it. Therefore, when the holes of the sliding base overlap with one of the holes of the static base the cylinder shaped piece will interface with both holes limiting movement. In order to unlock this mechanism the user has to press down on the cylinder to allow the sliding base to move freely.

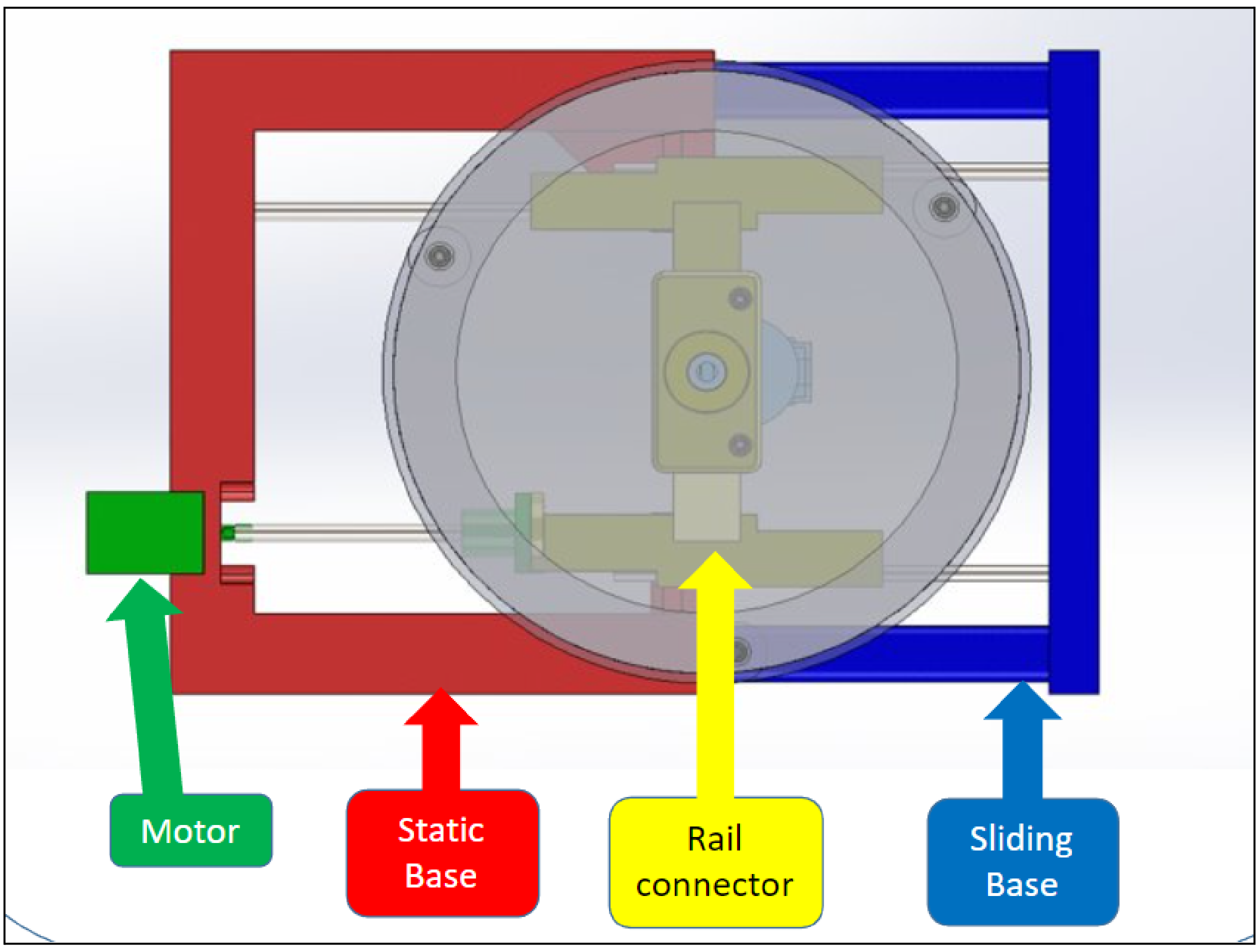

Figure 49: Final base assembly

7.2 Printing Bed

7.2.1 Bed Assembly Version 1-2

The original bed design, seen in figure 50, was a simple circular piece which was attached to the base using four rods. This design was unable to rotate. Therefore, the second iteration of the bed, seen in figure 51 and 52, implemented a slot for a motor, as well as splitting the bed into separate parts, to enable rotary motion. As shown, the rail connector was divided into four pieces, the rails (1 and 2), the rail connector, and the bed plate.

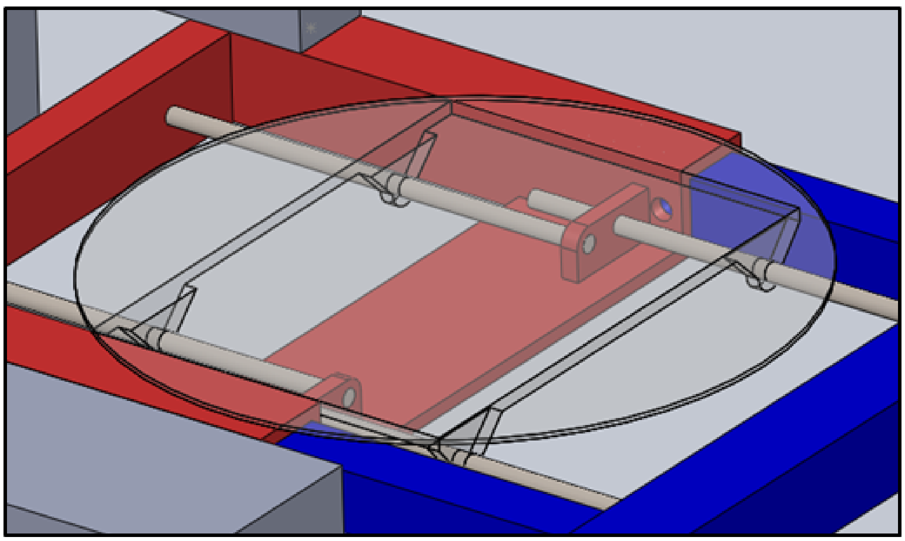

Figure 50. Original Bed Assembly

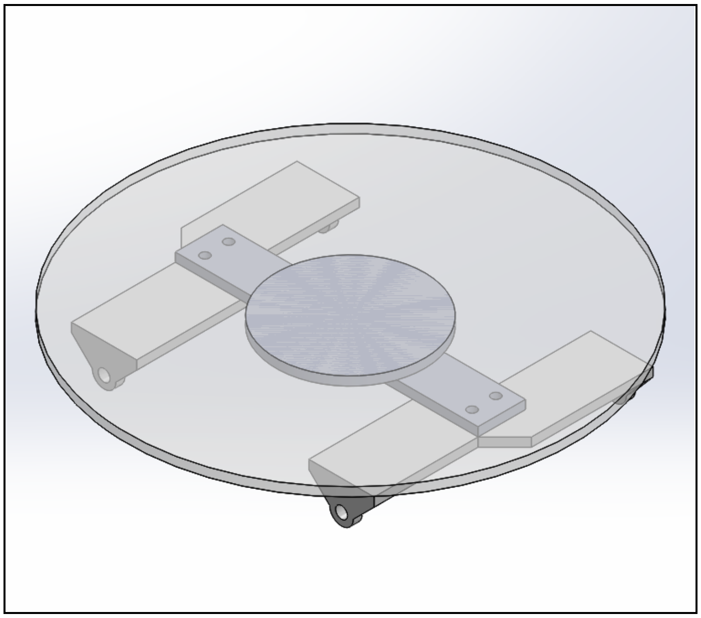

Figure 51. Bed Assembly V2 Above

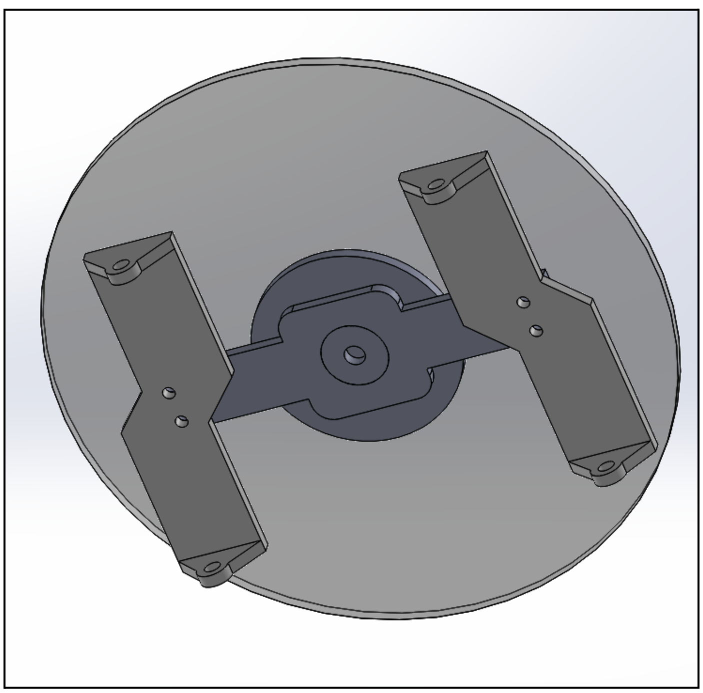

Figure 52. Bed Assembly V2 Below

7.2.2 Bed Assembly Version 3

The following iteration, seen in figures 53-54, implemented a leveling system. This system was inspired by the most common manual leveling mechanism for 3D printers: bed springs. The mechanism worked very similarly to other bed springs, the main difference was the tightening was done using a hand gear, rather than a screw. Furthermore, the NEMA17 stepper motor that was originally chosen was severely tall, exceeding the height limit for this application, thus we selected a 28BYJ-48 to take its place.

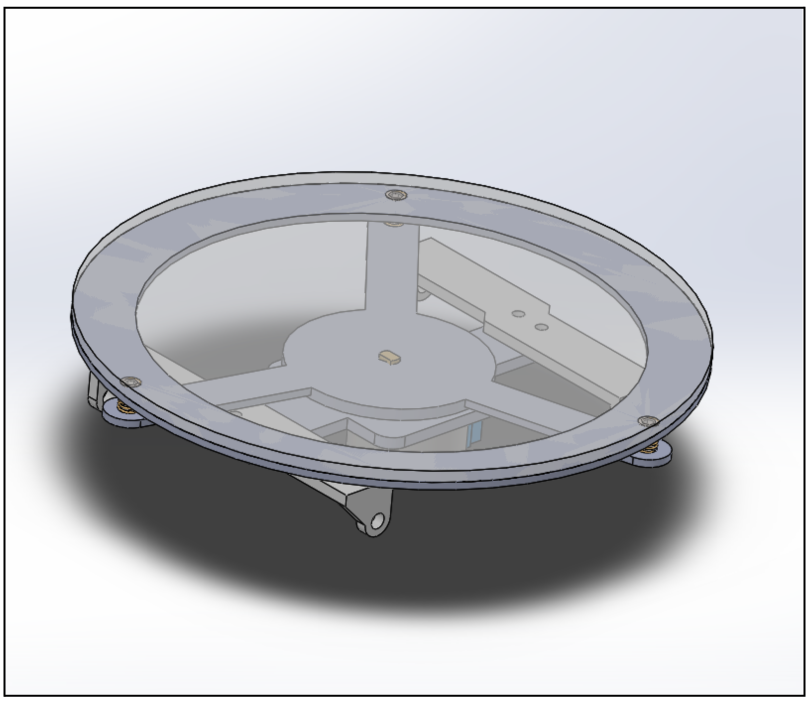

Figure 53. Bed Assembly V3 Above

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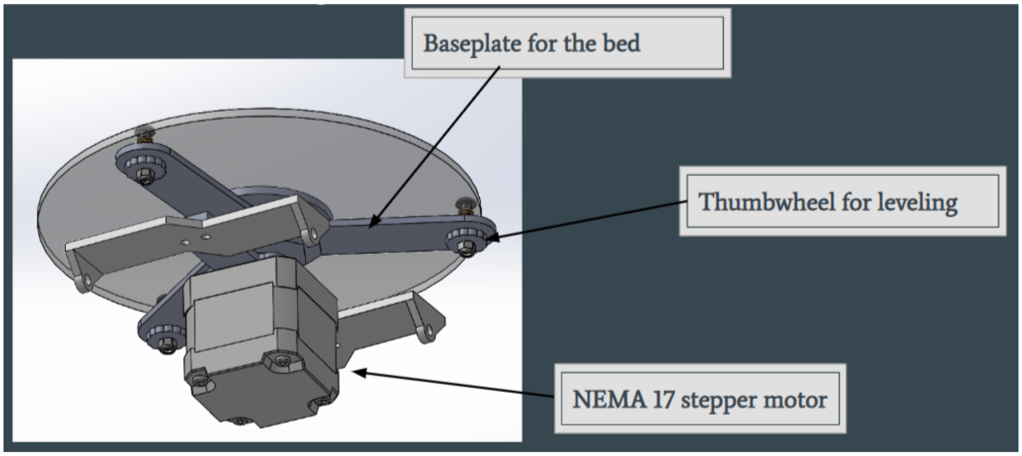

Figure 54. Bed Assembly V3 Below

7.2.3 Bed Assembly Version 4

As discussed previously, one major challenge for the bed assembly was height. Although a new thinner motor was chosen, it still interfered with the base. Therefore, the rail connector was designed to be slanted such that the stepper motor would more easily sit under the printing surface (Figures 55 and 56) and effectively minimize the total empty space in the model.

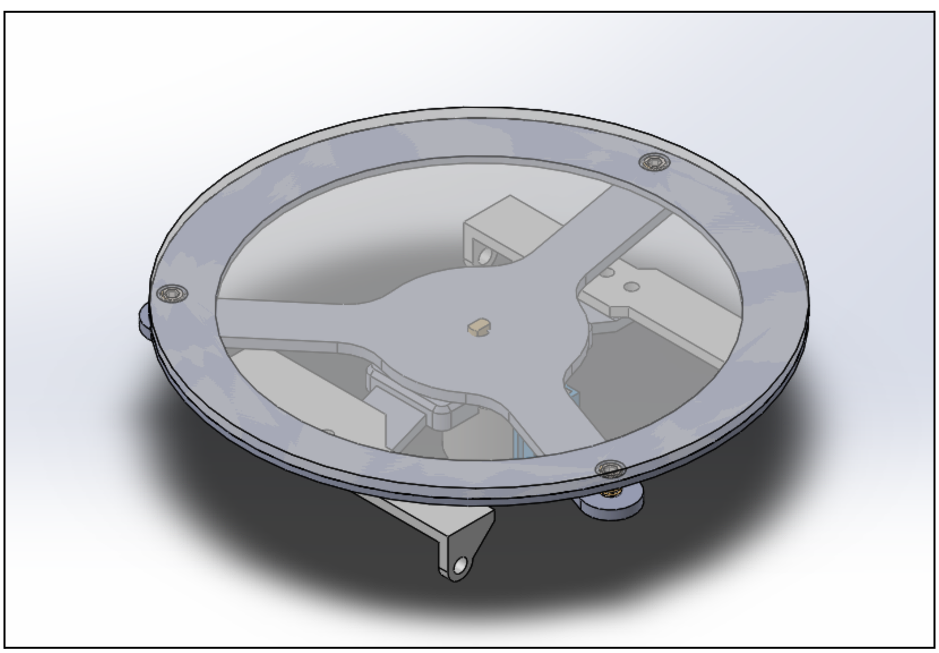

Figure 55. Bed Assembly V4 Above

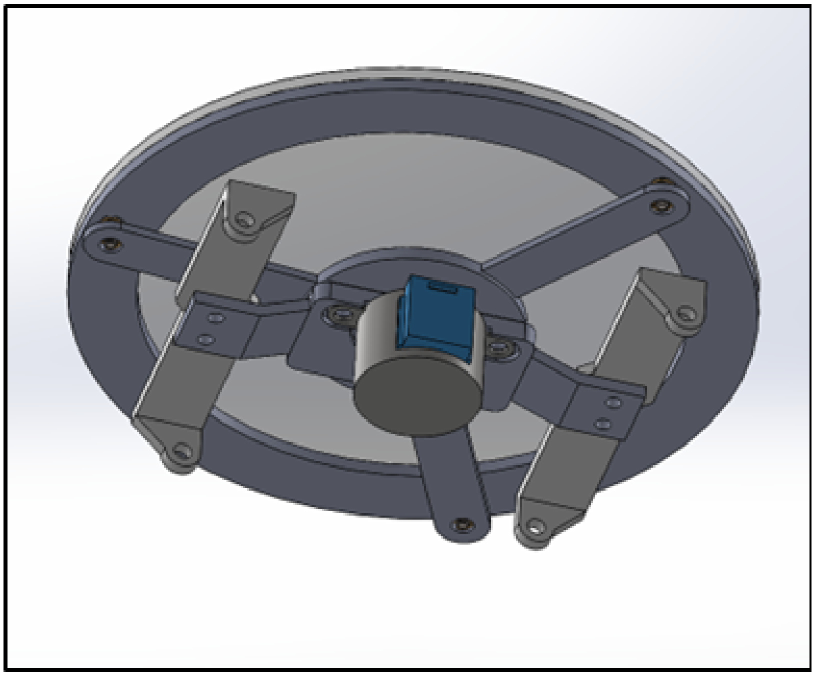

Figure 56. Bed Assembly V4 Below

When the bed was flushed out in SolidWorks, we began to 3D print and assemble the parts. Figure 57 below depicts the early stages of the bed assembly.

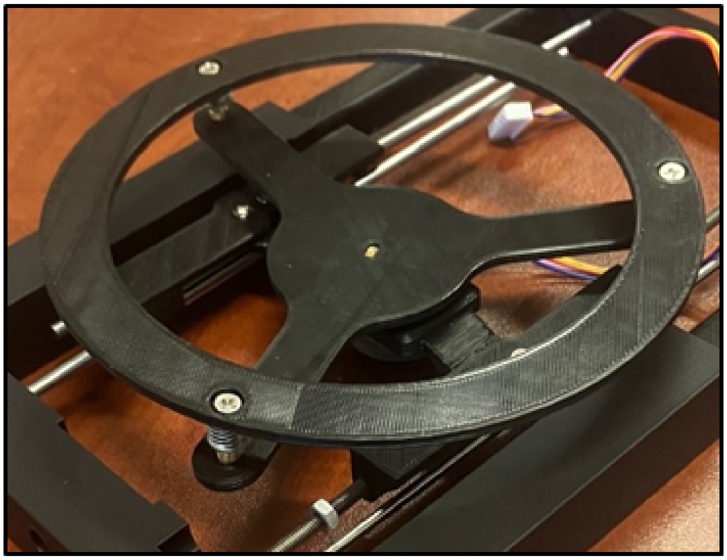

Figure 57. 3D Printed Bed Assembly

7.2.4 Rail Connector Version 5

Once the bed was assembled, the nuts were interfering with the bed holder. In addition, it was not as stable as we expected. Therefore, the 'rails' and 'rail connector' were combined to form one piece (Figure 58). This led the real connector to be more rigid as well as more space efficient.

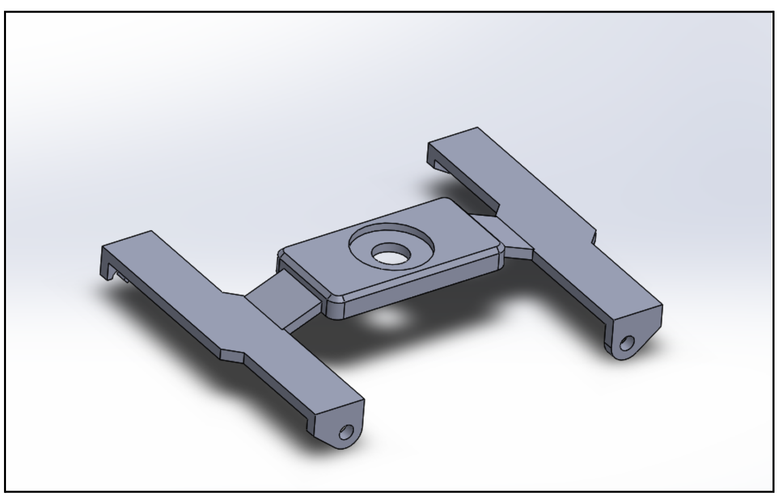

Figure 58. Unified Rail Connector

7.2.5 Baseplate

The baseplate is the PLA plate located on top of the rail connector. Its purpose is to interface with the motor and translate that motion to the Bed Springs. The original plate had an inner circle and three arms going towards the bed springs seen in figure 59. Due to the weight of the bed which is going through the bed springs into this piece, the piece would deform in the z-axis. Therefore, finite element analyses were conducted on four separate designs of the base plate. The results are shown in figures 59 through 62 below. The results showed that the original design experienced vertical deformation of 1.4 mm. Version four, the strongest design, experienced only 0.086 mm of vertical deformation. This made a considerable difference and considering the fourth design had no disadvantages, this design was adapted for all future bed assemblies.

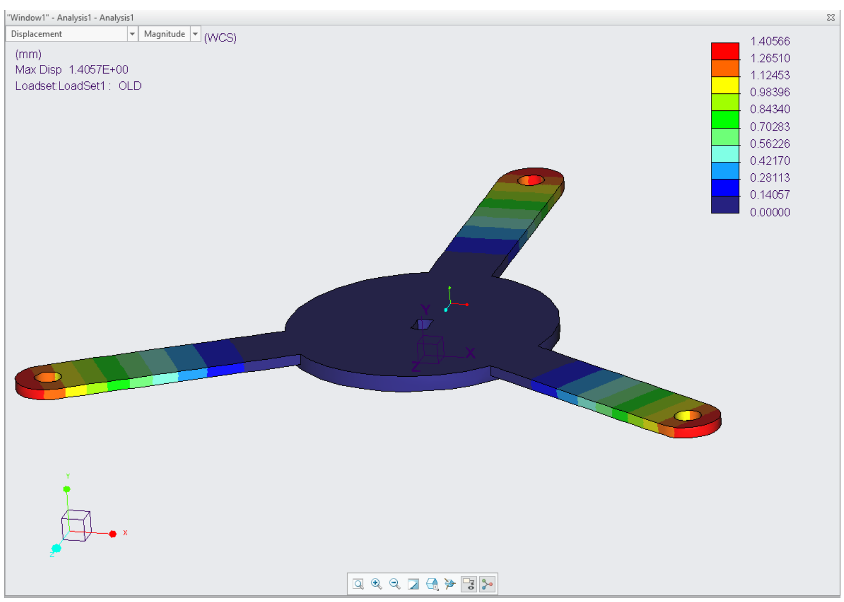

Figure 59. Bed Base Plate V1

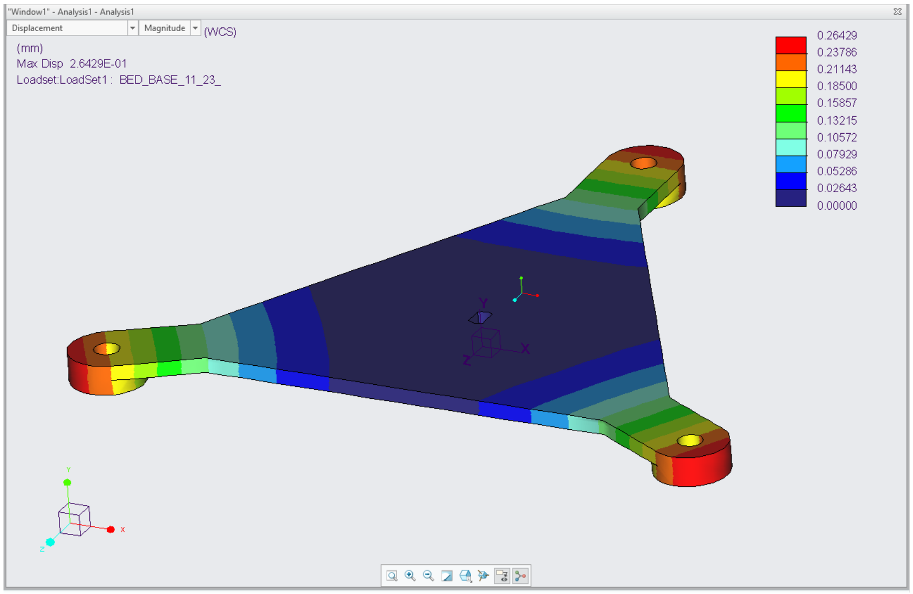

Figure 60. Bed Base Plate V2

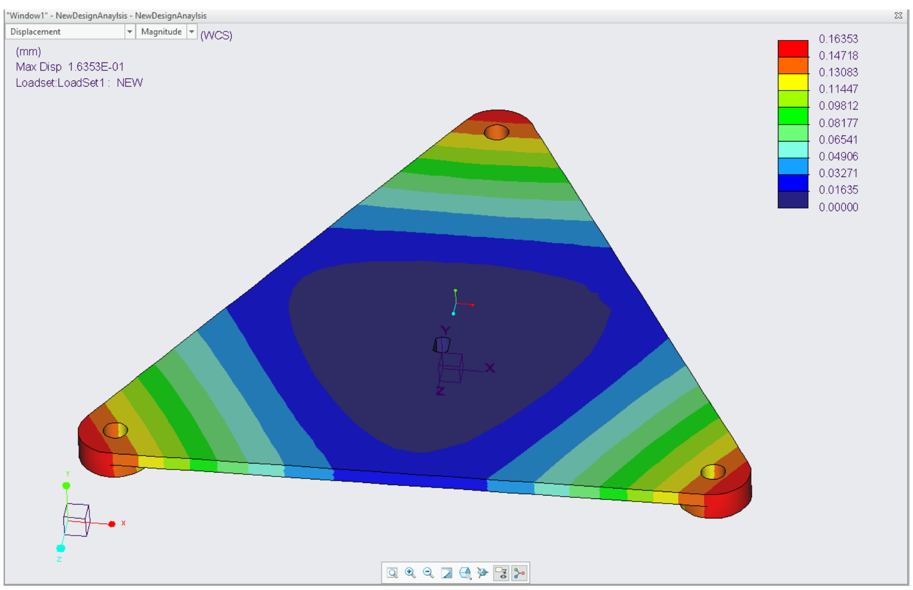

Figure 61. Bed Base Plate V3

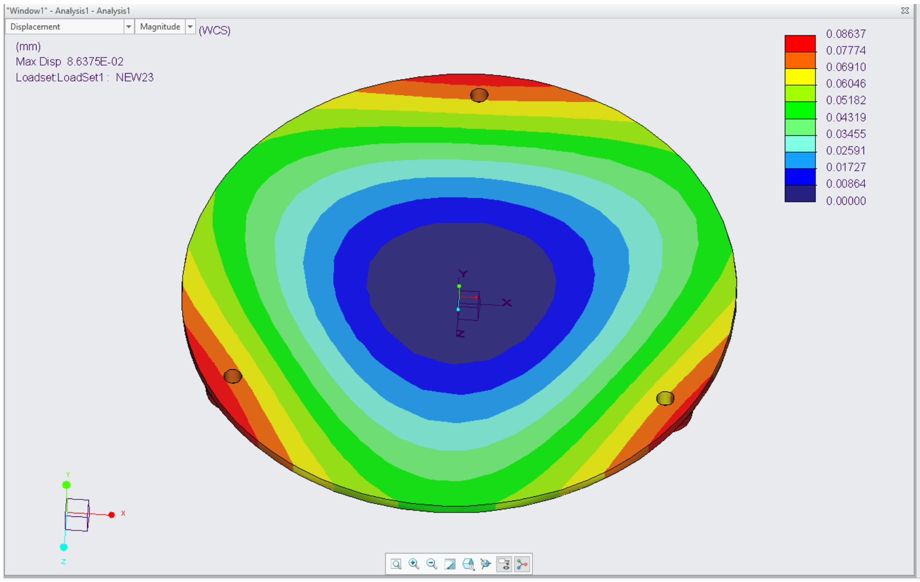

Figure 62. Bed Base Plate V4

7.2.5 Final Bed assembly

The final bed assembly is shown in figure 63.

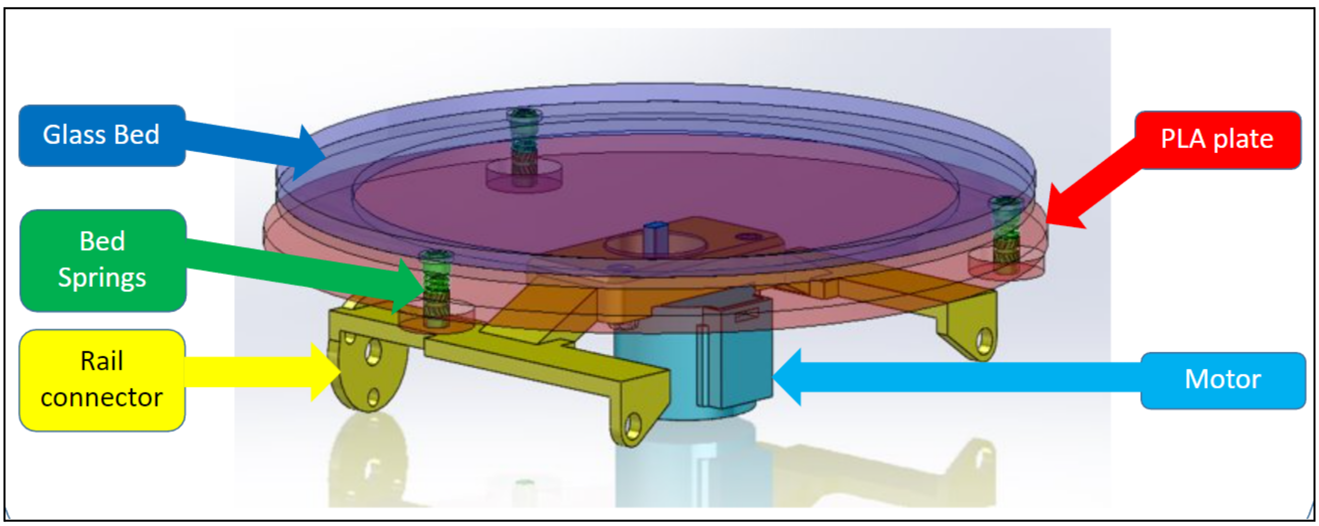

Figure 63: Final Bed Assembly

7.3 Tower

Early designs of the tower stayed relatively consistent up until later iterations of the printer. As shown in figure 64, a rectangular prism is extruded up through the z-axis. It is shelled out to make space for the Nema 8 stepper motor which has a bottom face of only 20mm x 20mm.

The bottom of the tower was also filleted to allow the tower to rotate about the x-axis without causing any collision issues. The height of the tower was just taller than the lead screw attached to the stepper motor.

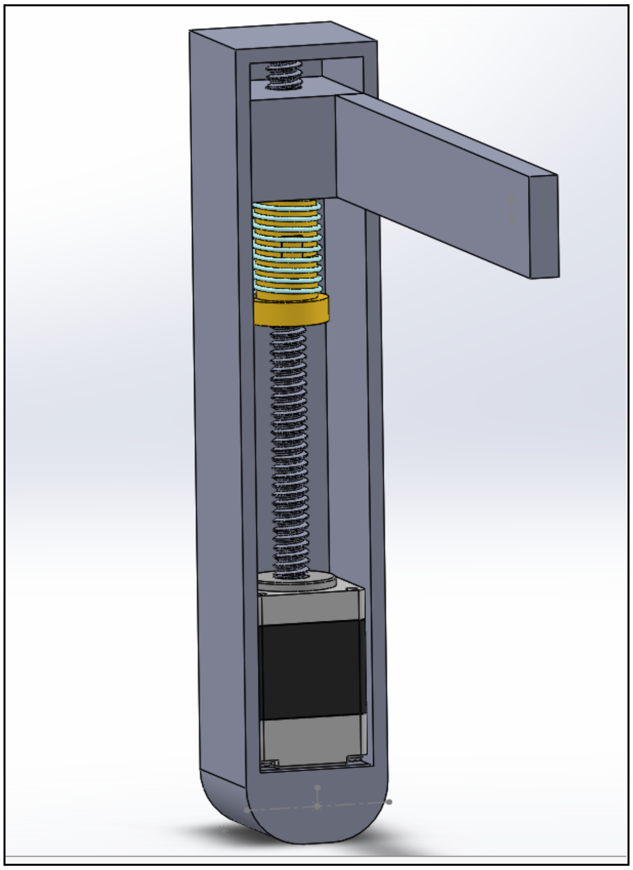

Figure 64. First Tower Design

The tower had to be changed due to the several swivel iterations that occurred. One tower iteration included the use of slots where magnets would sit to lock it into place shown in Figure 65. This design was scrapped in later iterations and was changed to its final form.

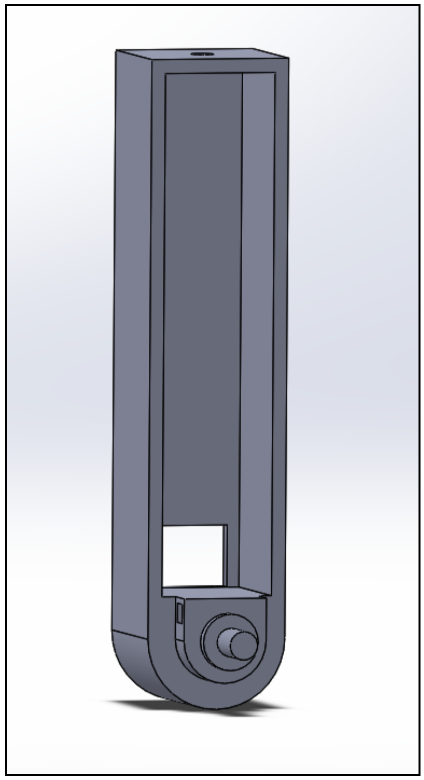

Figure 65. Second Iteration of Tower

Once the tower had all of its accompanying modifications including the guide rail, the pivoting system, and a cap tower was in its final design from shown in figure 66. The cap on the top of the tower was there due to the z-axis block needing to slide over the top of the tower and then resecured via the mention cap. The guide rail shown in this CAD model will be replaced with a 3mm steel rod in the actual design. The overhanged lip on the left face of the tower is to stop the tower from overextending past its inactive position.

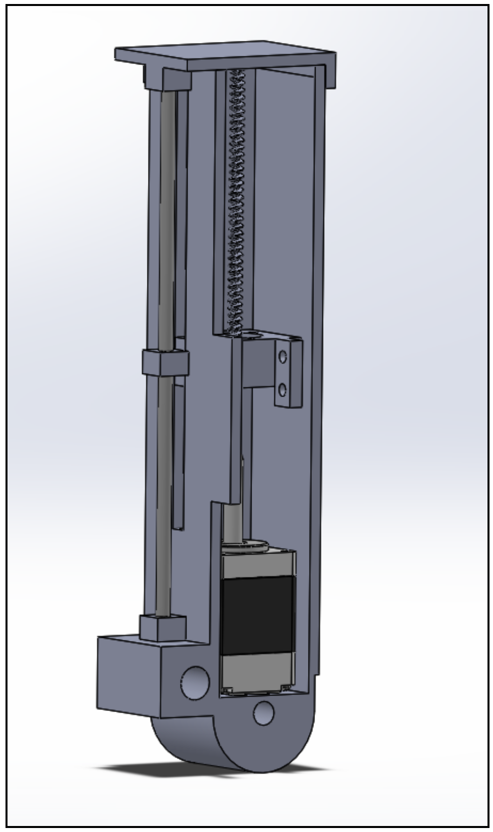

Figure 66. Final Design of Tower.

7.4 Full Arm Assembly

7.4.1 Arm Connector

The arm which is the piece that protrudes out from the tower in the x-dimension is responsible for holding the hot end and connecting it to the lead screw to move up and down. Figure 45 shows an early concept idea of how the arm would look. In order to maximize the range of motion of the z-axis the arm position was moved so that it rested within the anti-backlash nut and not on top of it. This can be seen in Figure 67 shown below.

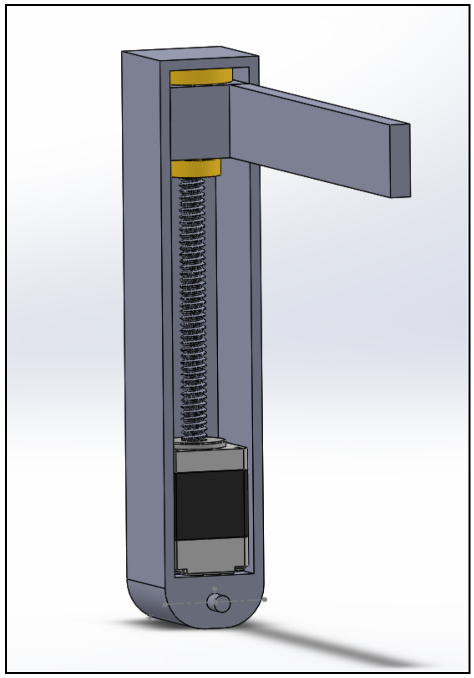

Figure 67. Tower With New Backlash Nut

Due to the hot end being directly connected to the arm a change in the material was necessary. The PLA would not be able to handle the heat therefore it opted out for a material that would not melt under high temperatures, acrylic. Figure 68 shows how the new arm will be broken up into two pieces. The long rectangular piece, the arm, will be laser cut from 3mm thick acrylic. The block on the left end will continue to be 3D printed.

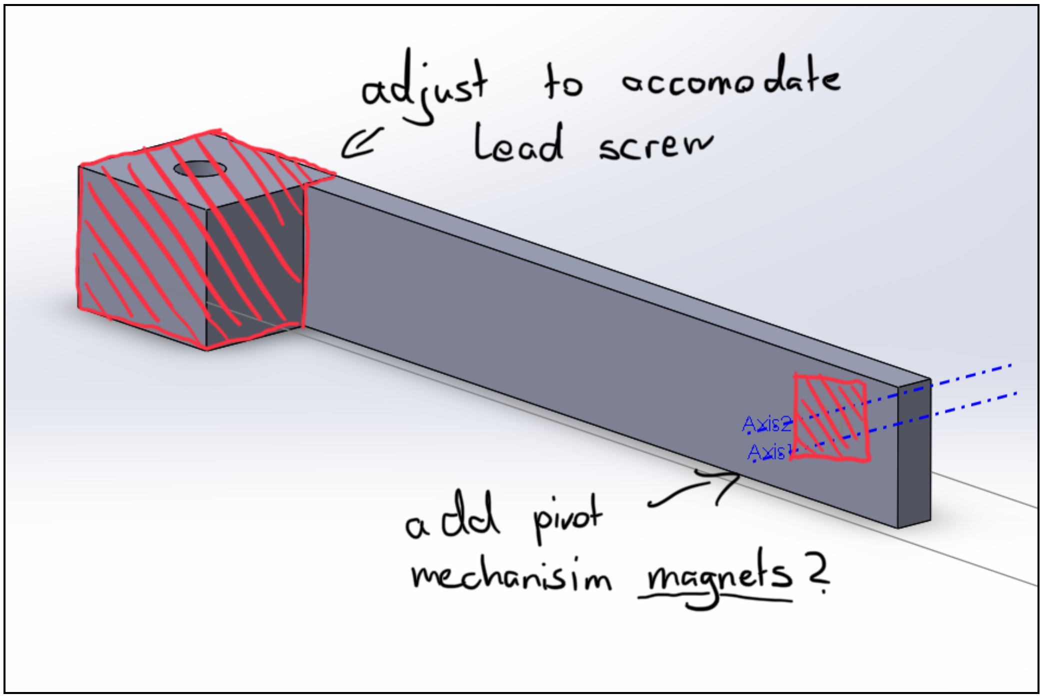

Figure 68. Arm Connector Split Into Two Pieces

Kevin and Esteban worked together to design the arm (the part that connects to both hot end swivel and tower) (Figures 69 and 70). As shown by the figures, a flat part was designed with holes for nuts and bolts.

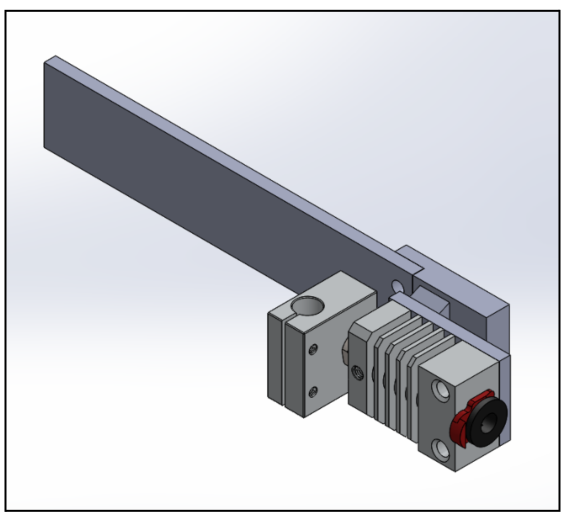

Figure 69. Arm Connector w/ Hot End (Inactive)

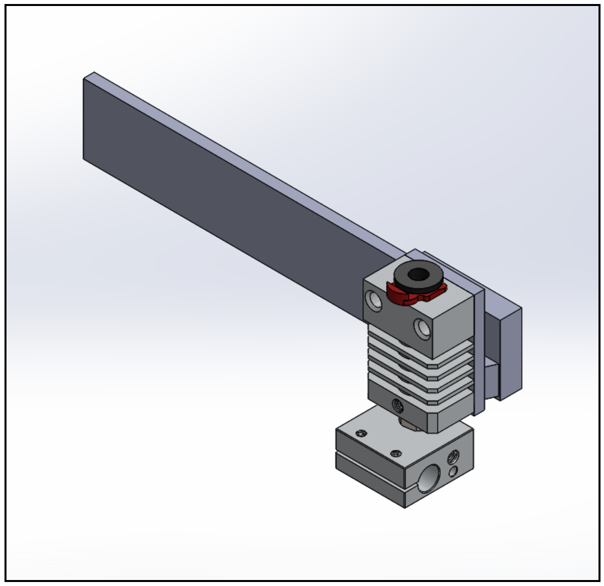

Figure 70: Arm Connector w/ Hot End (Active)

When the first version of the printer arm was completed in SolidWorks, it was edited to fit the tower and laser cut rather than 3D printed. Figure 71 shows the laser-cut arm attached to version 2 of the arm swivel.

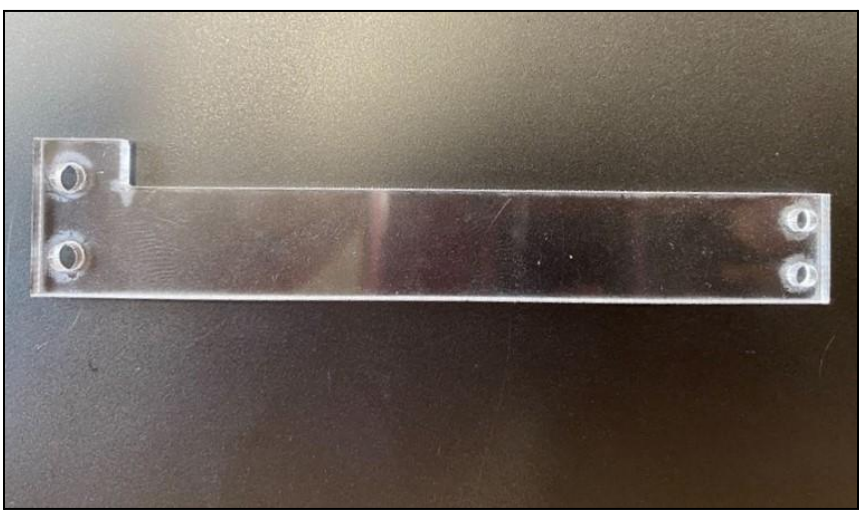

Figure 71. Acrylic Arm V1

7.4.2 Z-Axis Block

The block on the left (z-axis block) was modified to accommodate the guide rail system on its left side and the extra attachment that will activate the switch on the back of the tower. The hole through the center of the z-axis block is also widened so the anti-backlash nut can rest within it. Furthermore, the z-axis block will have 3 holes that will house 3 m2 screws connecting it to the anti-backlash nut. This final concept can be seen in Figure 72.

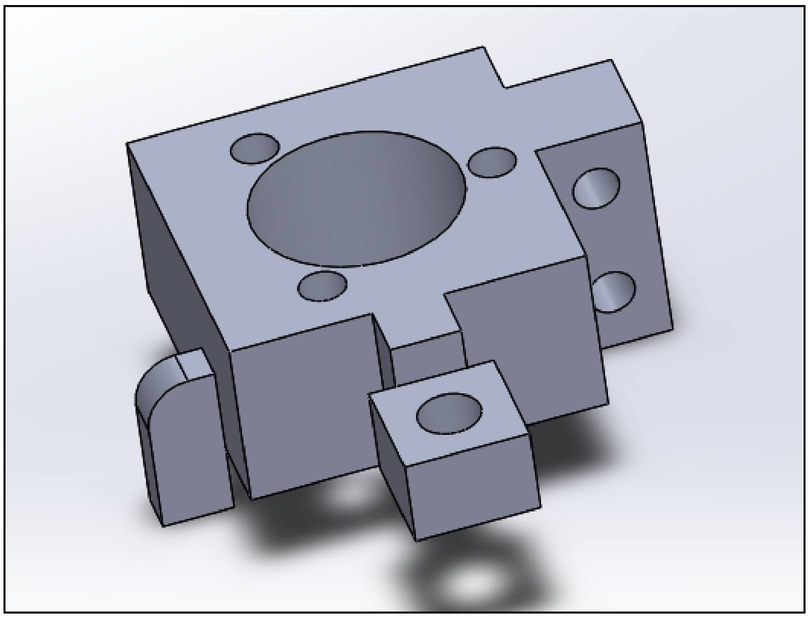

Figure 72. Final Design of Z-Axis Block

7.4.3 Hot End Swivel

Early versions of the Swivel mechanism specifically for the hot end connecting to the arm involved two separate pieces. The Hot end would attach to one side while the other side connected to the arm would remain stationary. The locking mechanism was accomplished through the use of magnets which had a strong enough pull to keep them in place. This was to allow the hot end to swing from an active position to an inactive position. Basic designs of this concept are shown in the two figures 73-75 below.

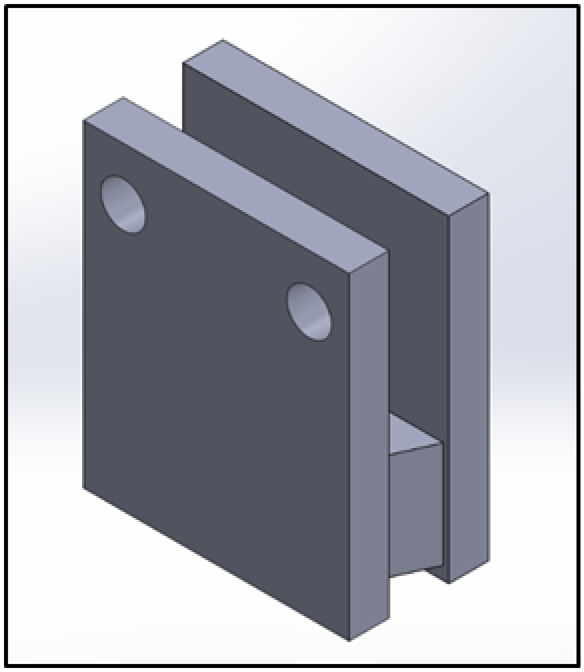

Figure 73. Hot End Swivel V1 (Active)

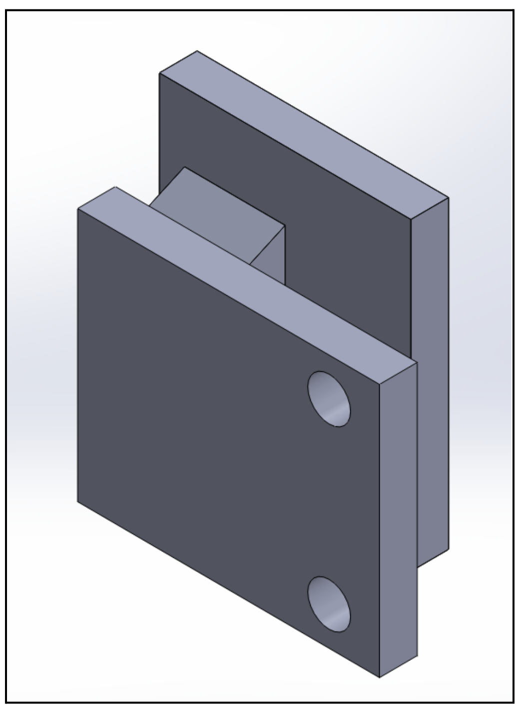

Figure 74. Hot End Swivel V1 (Inactive)

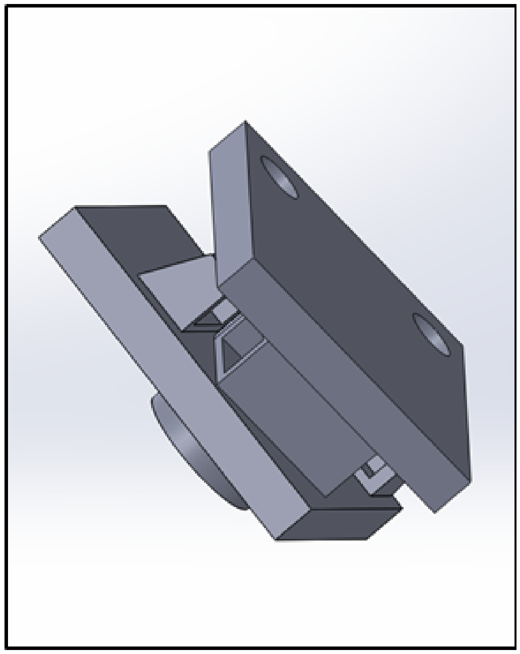

Figure 75. Hot End Swivel V1 Magnet Slots

After modeling the swivel mechanism in SolidWorks, the part was fabricated to see how the magnets would fit (Figures 76-77). From this test, the magnets functioned as planned and fit nicely into the slots with a little bit of super glue to hold them in.

Figure 76. 3D Printed Hot End Swivel V1

Figure 77. 3D Printed Hot End Swivel V1 Magnet Slots

From version 1 (Figure 76) to version 2 (gray, Figure 78) some minor adjustments were made. A hole was created to place a nut and bolt – the reason for this was the necessity of a more rigid material than a PLA peg.

After some revisions over version 2, the team observed that there would be a drag force from the PLA tube which forces the magnets to "unlock." This version 2.1 was created (green, Figure 78) to see if adding a magnet in the middle would hold the hot end better. Unfortunately, the magnet poles were interfering with each other. Finally, version 2.2 was created (blue, Figure 78) to see if double-stacking the magnets would produce a stronger hold.

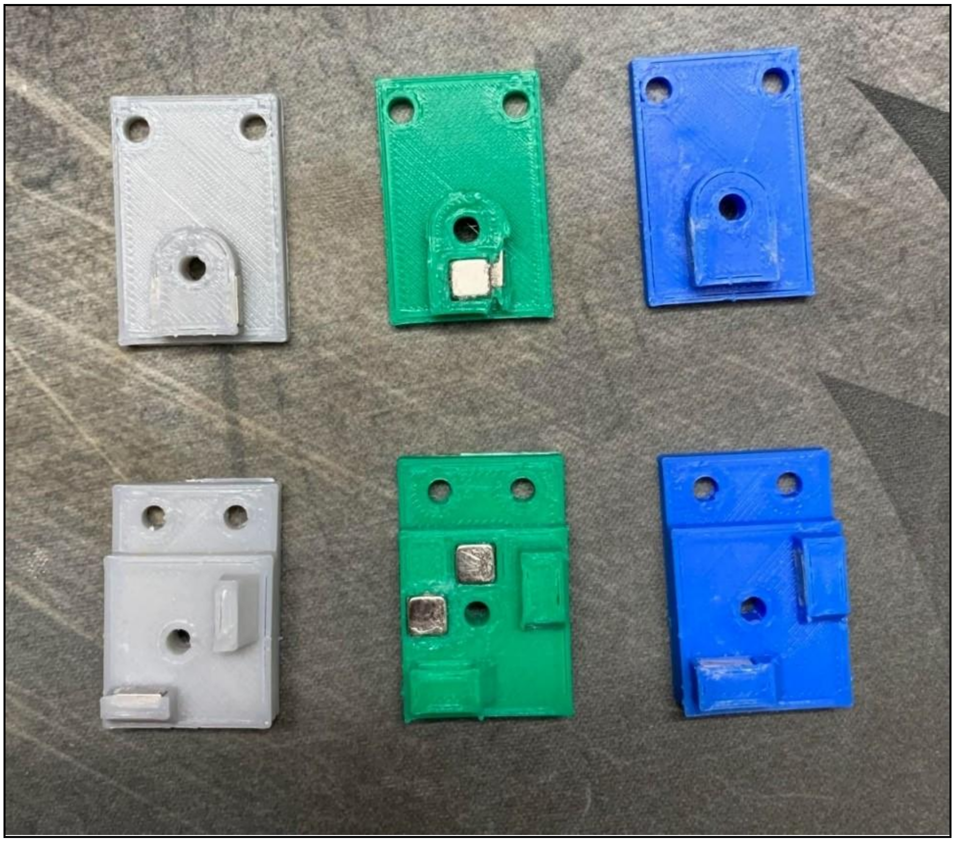

Figure 78. Hot End Swivel PLA Versions

When testing version 2.2 of the hot end swivel, there was still a potentially overpowering drag force from the PLA tube. To fix this, the team opted to use a pin to hold the hot end swivel in place (Figures 79 and 80).

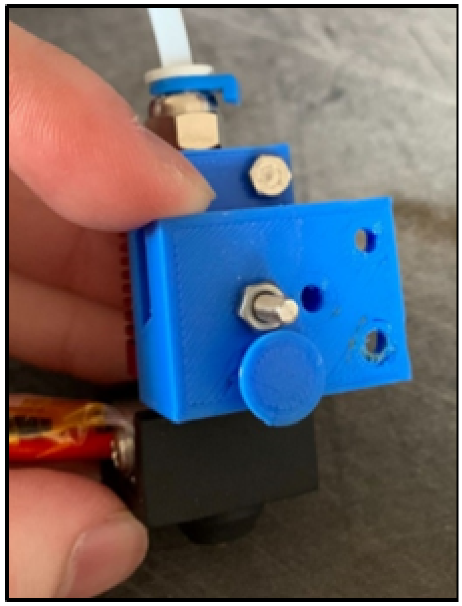

Figure 79. Hot End Swivel V3 (Active)

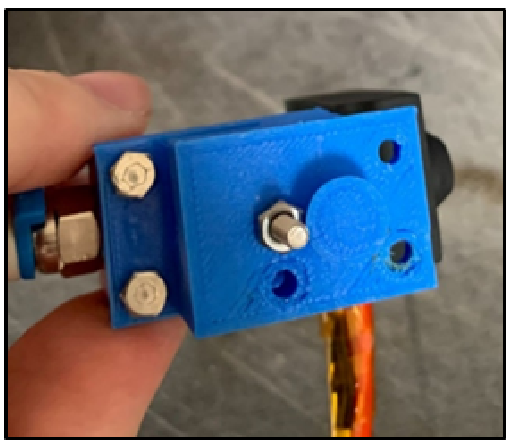

Figure 80. Hot End Swivel V3 (Inactive)

When the hot end swivel was finalized, three sets of parts were sent to be queued with different pinhole tolerances to the resin printer (Figure 81). Three pairs were queued at once since the turnaround time was quite slow and decided this would be faster. A successful pair used a metal pin to hold it in place (Figure 82).

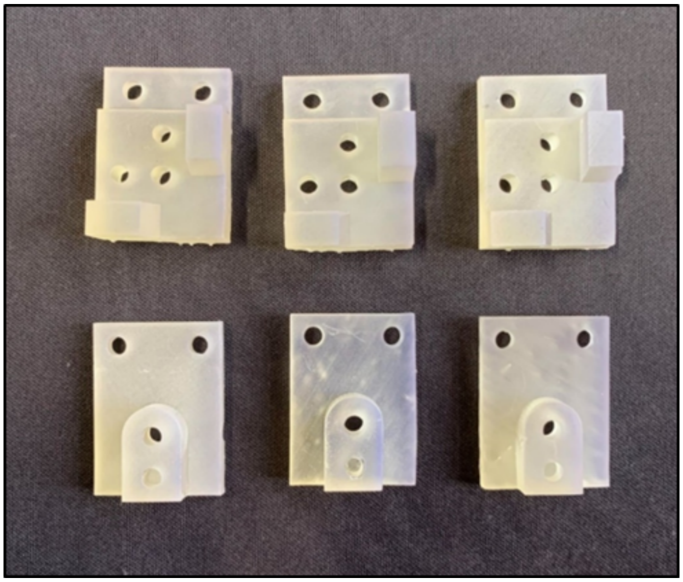

Figure 81. Resin Print Tolerancing

Figure 82. Resin Print Hot End Swivel V4

Unfortunately, when taking apart the working pair, one of the pieces snapped – this proved the resin prints were quite brittle. Originally, a higher heat deflection temperature was desired than PLA since this piece would be in the same vicinity as the hot end.

Inconsistencies between the CAD model and the prototype forced the team to reconsider some of the design ideas. First off, as the extruder swivel required a rod to hold it in place, it was no longer useful and put too much weight on the nozzle. To account for this, we introduced a simple arm design that attached the z-axis block with the extruder, whilst keeping the structure upright (Figure 83).

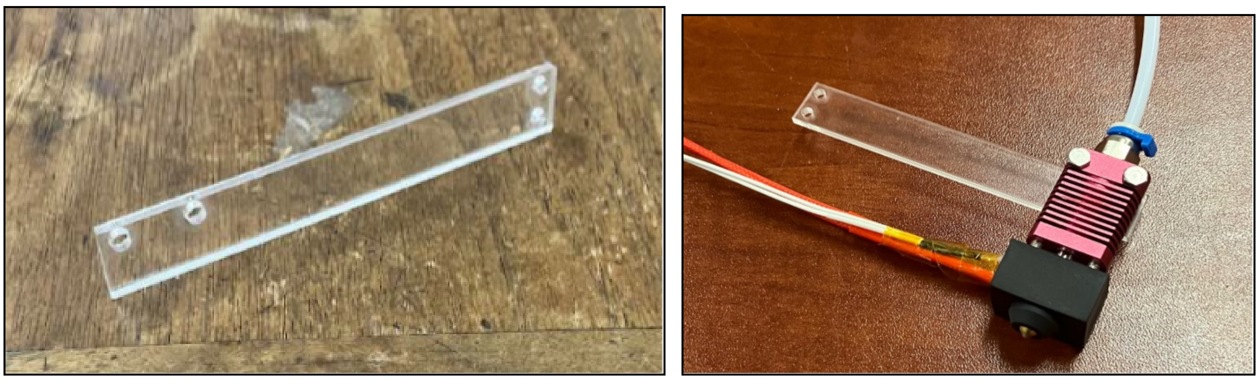

Figure 83: Acrylic Arm V2

7.5 Tower Pivot

7.5.1 Tower Pivot Version 1

Originally, we had a spring mechanism to hold the tower in place. The said spring would force a gear into position. Once printed, however, the tolerancing could not be tight enough for the stability required.

7.5.2 Tower Pivot Version 2

Therefore in the second prototype, magnets were used for the tower swivel (Figures 84-86). When compared to the hot end pivot, the main difference is an added magnet slot to prevent the tower from sliding out. In addition, a base insert was designed that can slot into the base to hold the magnets. This allowed for quicker manufacturing and iterating as the base, which was a 12 hour print, did not need to be reprinted for every new iteration.

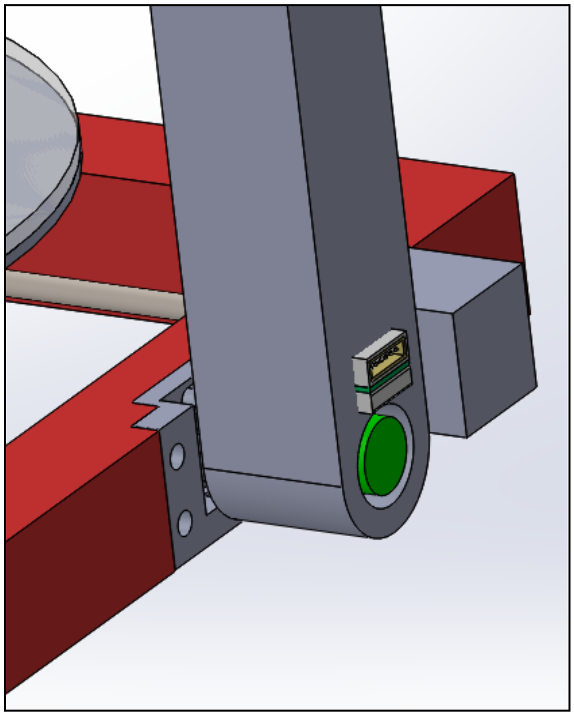

Figure 84. Tower Swivel V2

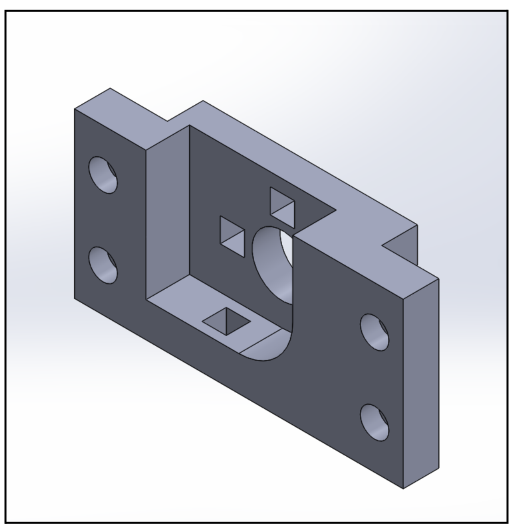

Figure 85. Base Insert V2

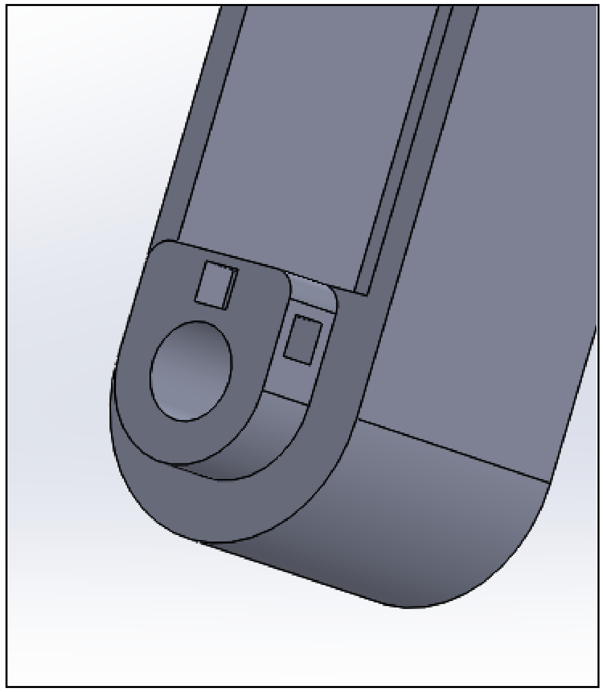

Figure 86. Tower Pivot V2

7.5.3 Tower Pivot Version 3

The Tower Pivot version 3 (Figure 87-88) used the magnetic mechanism to its fullest. In comparison to version 2, bigger magnets were used as well as tighter tolerancing in 3D printing. Additionally, bearings were added to support the pivot. However, this mechanism, similar to the spring mechanism, did not provide the necessary stability. Therefore, version 3 was the last version of the pivot using magnets.

Figure 87. Partial Tower V3

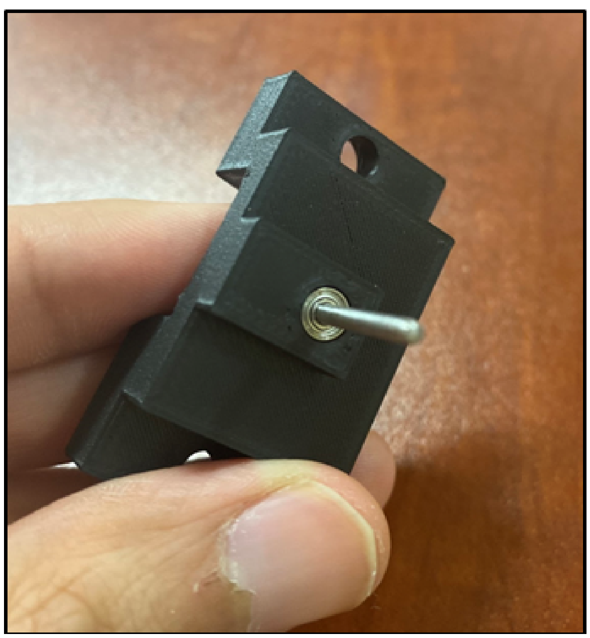

Figure 88. Base Insert V3

7.5.4 Tower Tower Version 4

The fourth version of the tower pivot mechanism incorporated a ball detent. This ball detent was fitted on the base of the tower seen in figure 89. It is held in place by a threaded insert, which is heated and pressed into the PLA. The ball detent interfaces with a slot in the base in order to hold the arm upright.

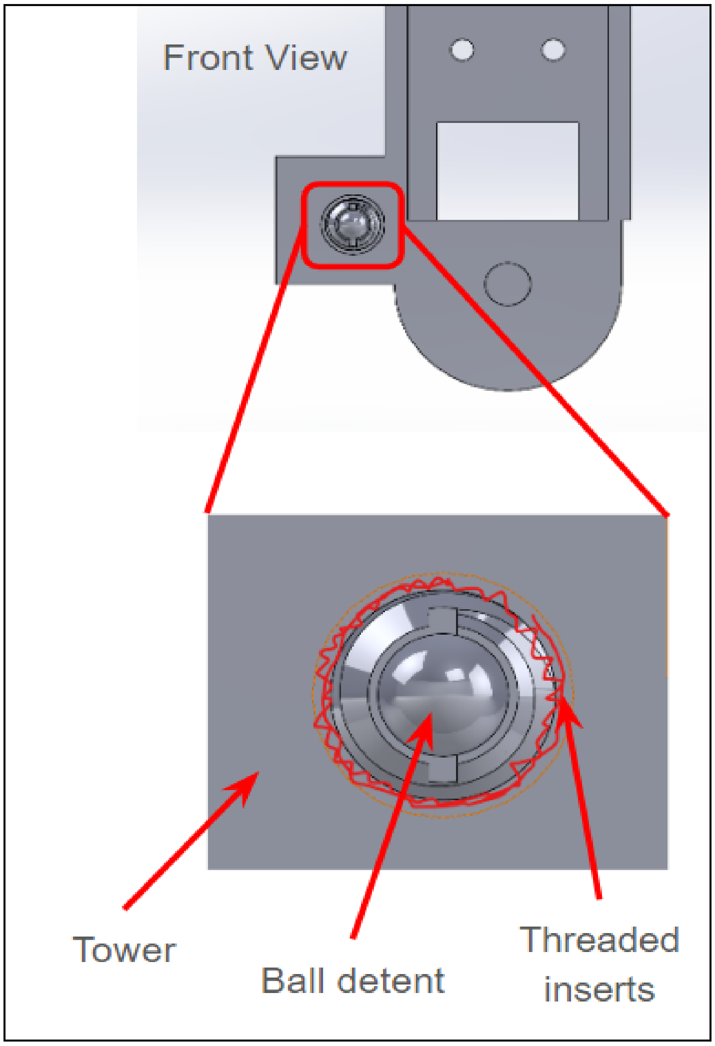

Figure 89: Tower Design V4 with ball detent

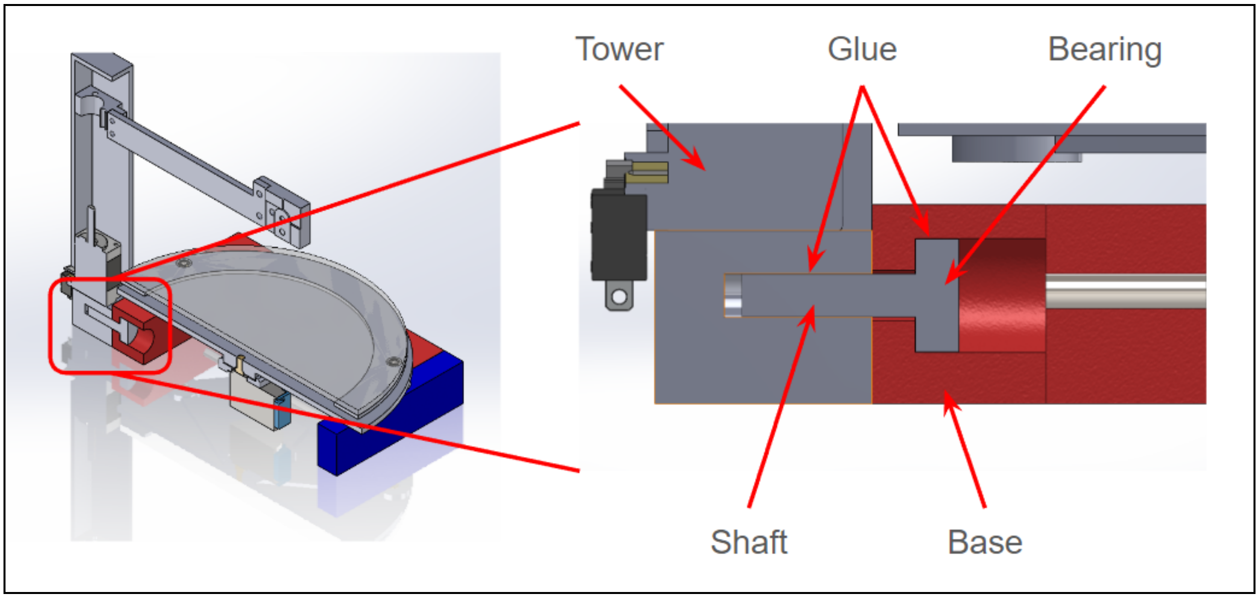

Figure 90: Tower Design V4 bearing design

Figure 90 displays how the bearing and shaft work to hold the tower in place. This assembly allows the arm to rotate but does not allow the arm to move back and forth or any other degree of motion.

8.0 Final Prototype

8.1 Final CAD Model

The final design of the printer is composed of 102 total parts with the breakdown of those parts as follows: 11 3D printed PLA parts, 2 laser-cut acrylic parts, 4 steel rods, 2 end stops, 3 stepper motors, 2 motor couplings, 4 springs, 5 brass inserts, 6 washers, 22 screws, 10 nuts and 1 direct titanium extruder hot end. The design, although unconventional in its style, serves many functions, with its foldable arm and tower and sliding ability of the base, as it can be easily transported from one place to another. Figure 91 below shows the isometric view of the completed CAD model.

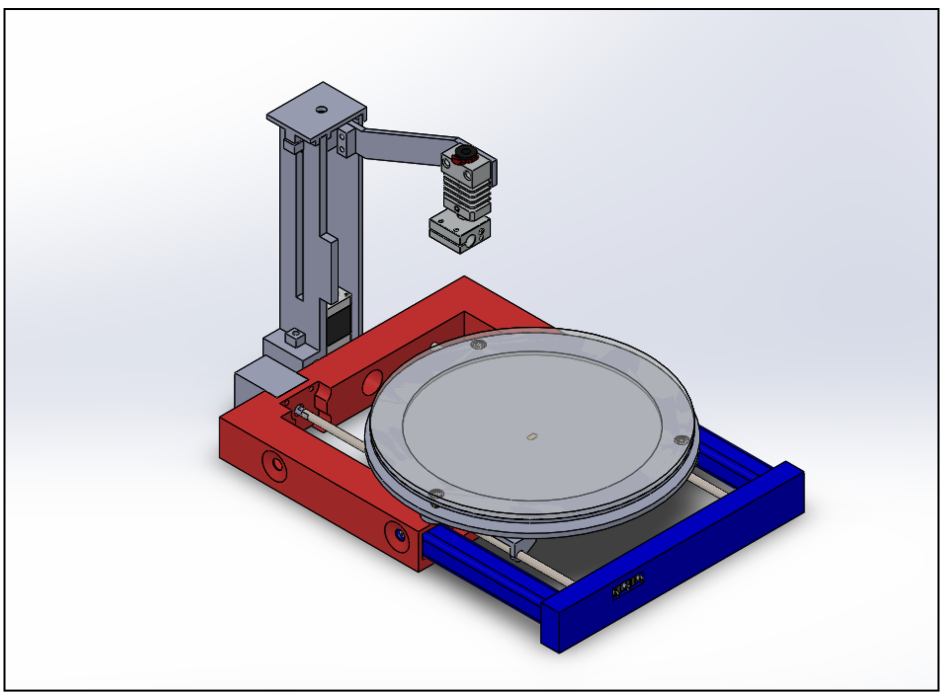

Figure 91: Final CAD Model

8.2 Final Design Considerations

Some design considerations that were made in the ultimate construction of this printer were the addition of panels on the top and front of the tower which serve to lock the z-axis stepper motor in place as well as a 3mm diameter guide rod which adds support for the z-axis. A spring-lock mechanism was also incorporated into the base to keep the structure stable during printing and resting positions. Figure 92 shows the completed model of our 3D printer.

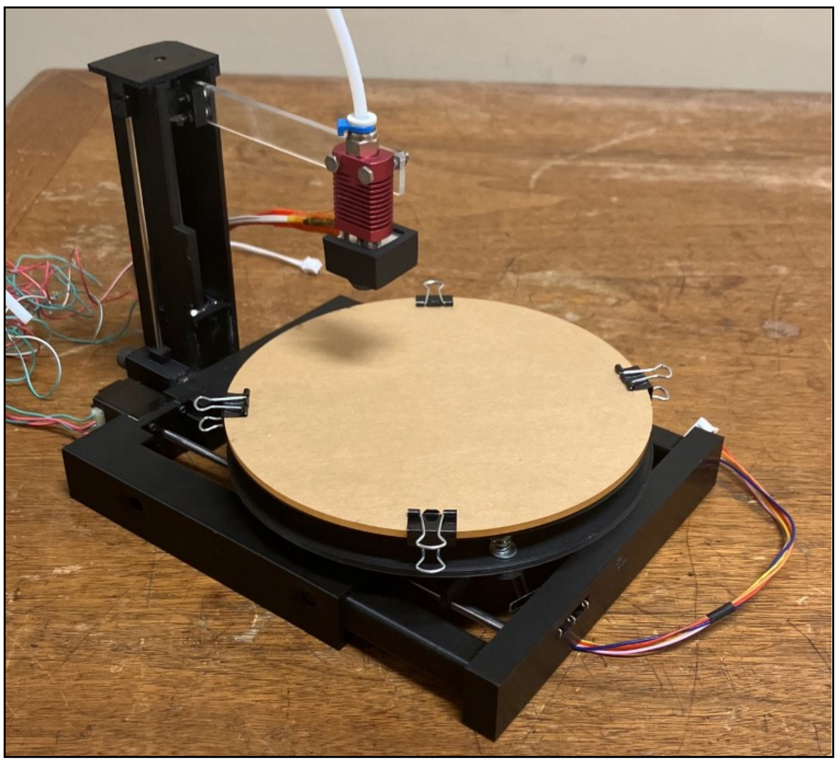

Figure 92: Prototype 3 (Final) Printing

Moreover, the printer's dimensions are 220mm x 140mm by 45mm for maximum portability and neatly fits into the palm of the user's hand, as the project name suggests, "Palm Print". The printer's collapsible appendage makes it especially useful for quick prints in specific environments where industrial printers may not be available. Figure 93 below shows the collapsed version of the printer, demonstrating its size in reference to the user's hand.

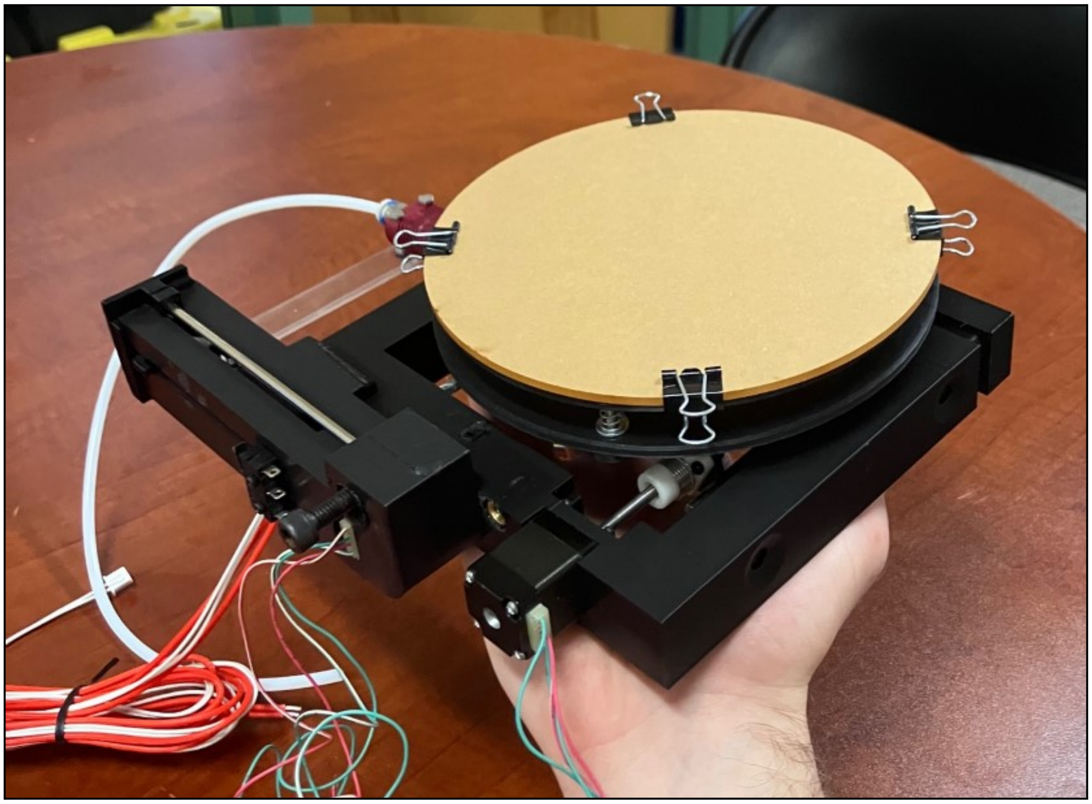

Figure 93: Final Prototype Resting

9.0 Conclusion

The goals of this Major Qualifying Project (MQP) were to design and fabricate a portable 3D printer, since there are not many portable alternatives on the market. Our sleek design achieves a large printing volume while minimizing hardware space and maximizing compactness. The team was forced to overcome many obstacles during this project, however by working together and having fun as a team, we were able to accomplish our goals.

10.0 Engineering Ethics

If this idea becomes a product, we believe it would have the potential to affect everyday people, especially students. Since this product would be about the same size (if not smaller) as a laptop, it would be quite convenient for students to leave in their bags.

10.1 Engineering Ethics

Engineering ethics revolves around people's welfare and safety. "Engineering Ethics is the set of rules and guidelines that engineers adhere to as a moral obligation to their profession and the world. Engineering is a professional career that impacts lives" (Nguyen). We believe that this project will prove to be more beneficial than harmful. When working on this project, we had the goal of producing a product that can help students.

10.2 Societal and Global Impact

As said earlier, this idea has the potential to affect students. For example, if a student needed to 3D print something on the spot, they would be able to take this 3D printer out from their bag and set it up. However, it would not just be students, it could be any enthusiast or even a professional engineer working in the field.

10.3 Environmental Impact

From what we can foresee, the environmental impact of this idea would be the carbon emission when producing PLA, but "according to research, the carbon emissions associated with PLA production are 80% lower than that of traditional plastic" (What is PLA?). Since this project heavily relies on PLA for both the construction and using it to 3D print. This would be something to keep in mind if this product is decided to be used or made.

10.4 Economic Factors

There could be two routes for this project to go down. If this project were an open-source project, the economic factors mainly revolve around the cost of acquiring and using PLA, since this project heavily relies on it (as said before). Another route would be to have this product manufactured. The main economic factors in this would be the cost of production, which would then lead to how much we would sell it to the consumer.

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