Mechanical Engineering Design

Final Project Report

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1. Introduction

One of the most interesting technological wonders in today's era is a 3D printer. Such a printer is capable of printing a three dimensional solid object of any shape by using digital set of instructions. The key to three dimensional printing is additive process where successive two dimensional layers of printing material are laid down to create the final design.

1.1. Purpose:

This report explains the design process undertaken to create a detailed conceptual design for a 3D printer targeted at audience using it as a hobby. It involves outlining engineering specifications for the potential candidate designs which are based on user's needs, existing models and available literature. Three candidate designs are conceptually modeled to fulfill user's needs. A final design is chosen from the three candidate designs based on its ability to best meet the chosen engineering specifications. The final design will be modeled using CAD software.

1.2. Existing Designs

There are different 3D printer models in the market, which were used as a reference during the idea generation process. These designs include different models by Reprap, Hewlett Packard, Botmill, Felix, and Delta. These designs differ in the choice of axis systems for the motion of the extruder, general frame and mechanical systems. All these hobbyist models lie within a price range of $300 - $2500 [1].

1.3. Scope of the Design

The scope of the final design is limited to the mechanical system. This includes conceptually designing the frame, mechanism for motion of the extruder, and all the mechanical parts used. It does not involve electrical components and programming, but a system can be programmed later on by the user himself.

2. Engineering Specifications

2.1. Cost:

The cost of existing 3D printers range from $300 - $2500 [1]. However, we estimated that a price point of $2500 can be too expensive for hobbyists, therefore, we are aiming for an estimated purchase cost of $1000. In addition to the purchasing costs, there are ongoing operating costs for the printer. To keep those costs low, the printer will need to use existing common materials. PLA and ABS were found to be the most common materials in use. Therefore we chose to only support PLA and ABS [2].

2.2. Printing Materials:

The printer should be able to support common hobbyist materials that are easy and cheap to obtain. PLA and ABS had the highest availability, based on the number of suppliers for those materials in comparison to others, such as PVC and PC [2]. Thus, due to the low cost and high availability of those materials, we have selected PLA and ABS to be the materials used for printing.

2.3. Operating Principles:

There are numerous types of operating mechanisms that are possible for 3D printing. Common methods are Selective Laser Sintering (SLS), Stereolithography (SLA), Jetted Photopolymer (J-P), and Fused Deposition Modeling (FDM). SLS uses a high powered laser to facilitate the printing process, by fusing powder together. This produces high quality and durable products. SLA uses liquid resin, which is then hardened by radiating UV or laser to the resin. This creates high quality products, however, they are brittle and can be broken easily. J-P uses a similar approach where a photopolymer is hardened through UV light. It is primarily used for creating rubber-like objects. Finally, FDM uses a plastic filament which is melted and laid down in layers. This method is the most common method currently in use by hobbyist 3D printers, and has low cost and high availability materials. Hence, FDM was selected as our operating principle of choice [3].

2.4. Specifications:

The design should be able to meet a certain set of specifications, termed as engineering specifications. After extensive research and analysis, the following specifications have been laid down for the candidate designs:

1. The extruder should be able to navigate to any location within the build volume
2. Based on existing FDM 3D printers, the most common maximum size for printed parts was found to be approximately 200mm x 200mm x 200mm [4]. Therefore, to remain competitive, the design outlined in this report should adhere to that maximum size.
3. The printed part should be accurate up to 25 microns
4. There should be minimal vibrations during the printing process to ensure minimal defects in the end product
5. The mechanical systems should not jam
6. The design should be safe
7. the design should be require minimal maintenance and minimal lubrication
8. The design should be suitable for an indoor environment
9. The printing process should not be noisy (less than 60dB) [5]

2.5. Design Goal:

Looking into existing literature, and listening to the open source community, it seems that most models in the market today are not designed with prominence to aesthetic appeal. These models provide an ‘industrious’ which can be considered a disadvantage for the hobbyist community, who use these printers in their offices or even in their bedrooms.

Keeping this in mind, it is our goal to design a printer that will match the quality (or have better quality) and also provide a classic look which will appeal to the hobbyist crowd.

3. Candidate Designs

3.1. Axis System:

The choice of the axis system is one of the major choices that will affect the design of the 3D printer. When deciding on the axis system we considered two major axis systems which can be used in the price range we were looking at. Other systems with higher number of axes were deemed too complicated as well as too expensive.

After recognizing the axis systems, their advantages and disadvantages were compared based on their ability to print a cylinder, a cube and a triangular prism. Assumptions were made where necessary and will be stated as such.

3.1.1. Rectangular Coordinate System:

This system involves using linear motion in three axes, allowing for three degree of freedom motion. Lead screws or belts are usually used to move the extruder along these axes.

3.1.2. Cylindrical Coordinate System:

i) The Traditional System:

The traditional cylindrical system involves a shaft around which an arm can revolve, mapping out a circle. The extruder has to be able to move radially on this arm, and the arm has to be able to move along the Z-axis.

The picture below shows a geometrical interpretation of this model.

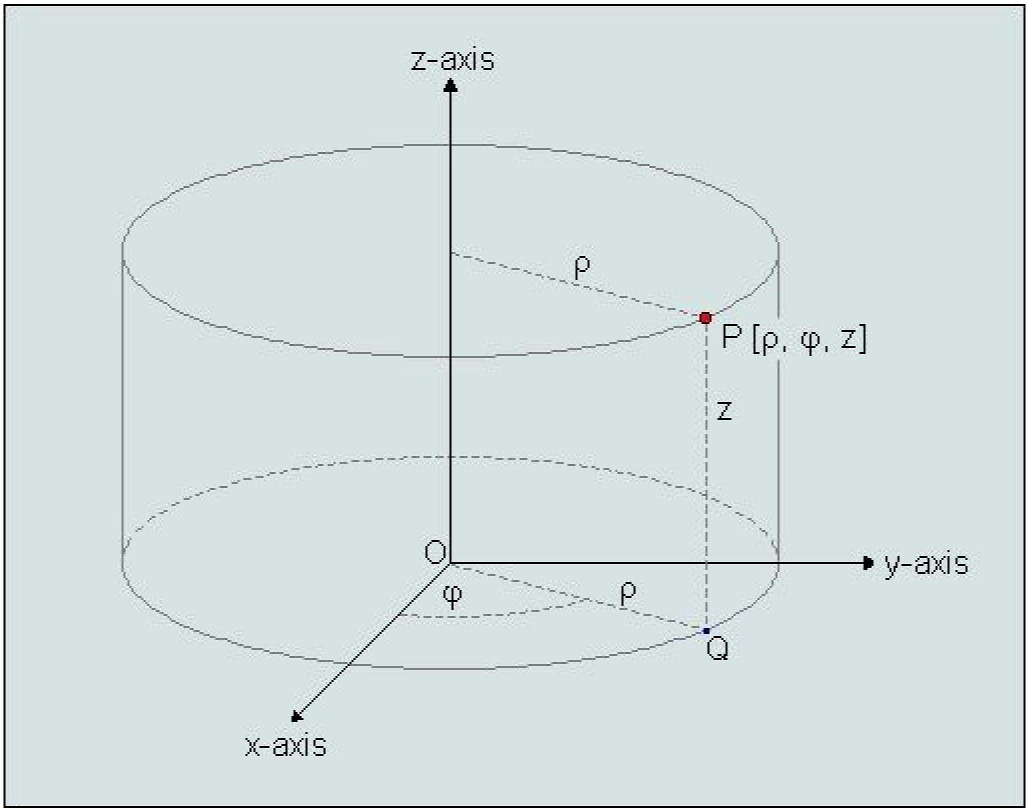

Figure 1: Cylindrical coordinate system [6]

Comparing this to the rectangular system, it can be seen that this has the advantage of being able to print a hollow cylinder more efficiently due to its geometry. However when it came to the cube and the rectangular prism (hollow and solid), this system would have to use two actuators simultaneously to achieve the task (one to move the feeder radially and another to rotate the arm about the main shaft. Hence this system was considered inferior to the rectangular system as this would result in greater time and power consumption and noise.

ii) Delta Printer:

The Delta printer which uses three actuators to move the extruder, has gained a considerable amount of attention in the open source printer community. As this system involves a complex movement system, judging the system would be hard without a relatively higher understanding. Therefore this option would be further looked into as a candidate design.

4. Design Analysis and Description

4.1. Candidate Design 1:

4.1.1. Design Drawings:

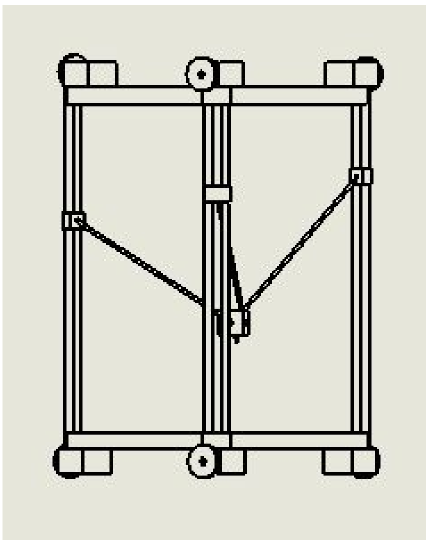

Figure 2: Front View

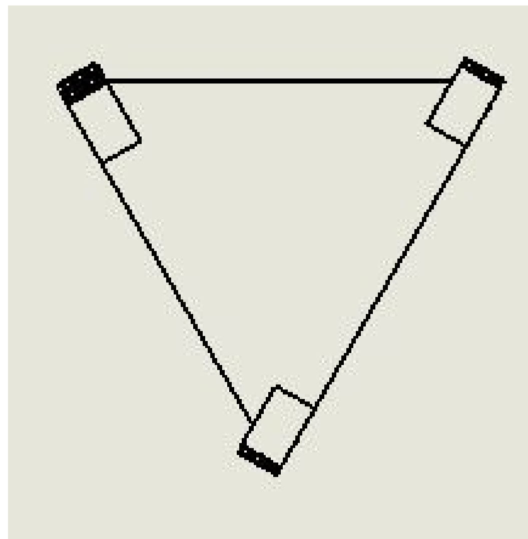

Figure 3: Top view

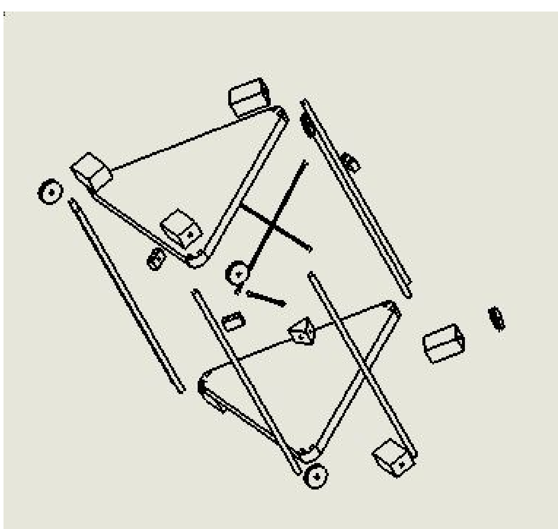

Figure 4: Assembly view

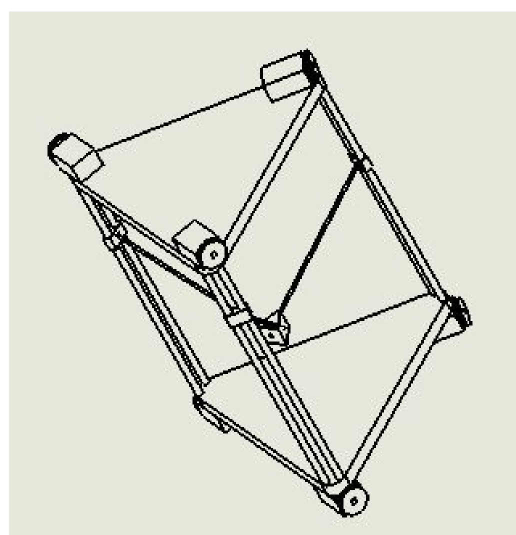

Figure 5: Isometric View

4.1.2. Design Description:

The delta printer works by controlling a hanging extruder supported by three external columns. The extruder hangs in the center of the printer and changes location by adjusting the height of the three support columns. The heights of the columns dictate the position on the bed that the extruder can reach. Using three columns, each with their own independent mechanisms to adjust height, the extruder is able to reach all points within the given circular bed.

4.1.3. Movement Mechanism:

The height of each column is adjusted by using a belt hanging along a guide rail. A stepper motor is mounted at the base and allows for precise control of the belt. A guide block will be attached to the belt and will move along the guide rail. This guide block is intended to provide stable support without tipping over for the beam that holds the extruder block.

The extruder block will be held in the air by three beams. Each of these beams will be connected to guide blocks on the exterior columns. The beams will be connected by modified ball sockets that would partially restrict motion in two directions to ensure the beams only move up and down, with a small degree of freedom to allow for movement in other directions as needed to accommodate the height difference of other columns. This would allow for the extruder block to change position in one axis, for each column. A pin connection was not selected as it would restrict motion to only one axis, which would prevent the extruder block from reaching all locations on the bed. The same type of ball sockets will be used on the extruder block and the guide block.

	Ball Socket	Pin Connection
Motional Freedom	Yes	
Ease of Replacement	Yes	
Accuracy		Yes

Table 1: Comparison of Ball Socket Connection vs Pin Connection

4.1.4. Extruder and Bed:

The filament used by the extruder will be slotted in from the top of the extruder block. The spool will be located on the side, on an external holder. A motorized extrusion mechanism will be used to push the filament through the extruder, in a similar manner to the other designs.

The bed will be located at the base of the printer, and will not move. Only the extruder mechanism will move.

4.1.5. Design Analysis:

There are several flaws with this design that make it unsuitable for selection as the final design. One major flaw is the axis system. The complexity of the axis system as compared to other systems can increase the amount of maintenance required overall. Additionally, accuracy and precision can be lost if all components are not properly positioned and remain in that position for the duration of the printer lifetime. Ensuring these factors will only increase the cost of the printer, making it less suitable for a hobbyist environment. Complexity issues are why this type of coordinate system was not chosen, and a cartesian coordinate system is preferred. The cartesian coordinate system will be further explored in Candidate Design 2 and Candidate Design 3.

4.2. Candidate Design 2:

4.2.1. Design Drawings:

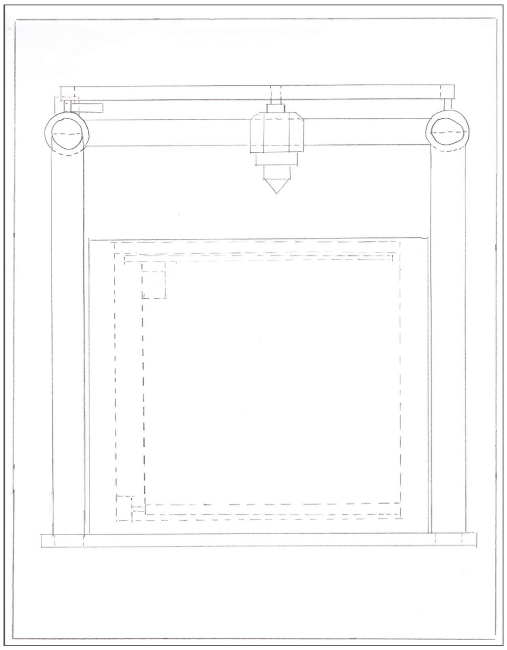

Figure 6 : front view

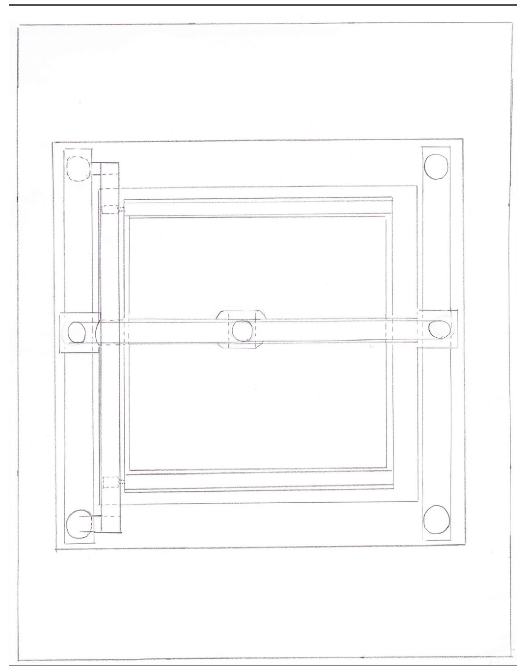

Figure 7 : Top view

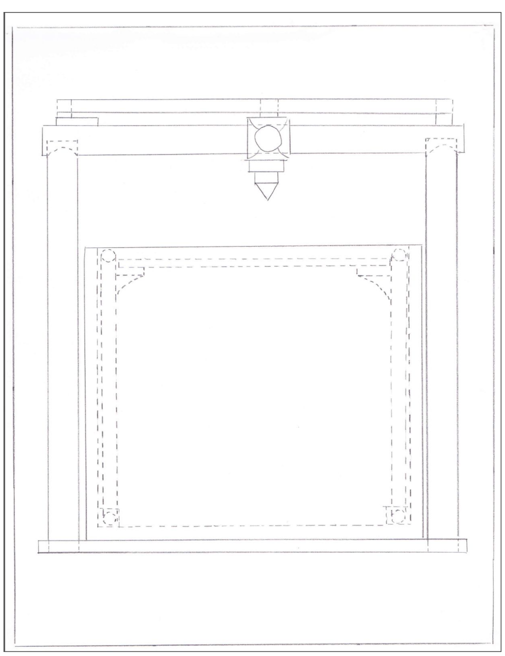

Figure 8 : right side view

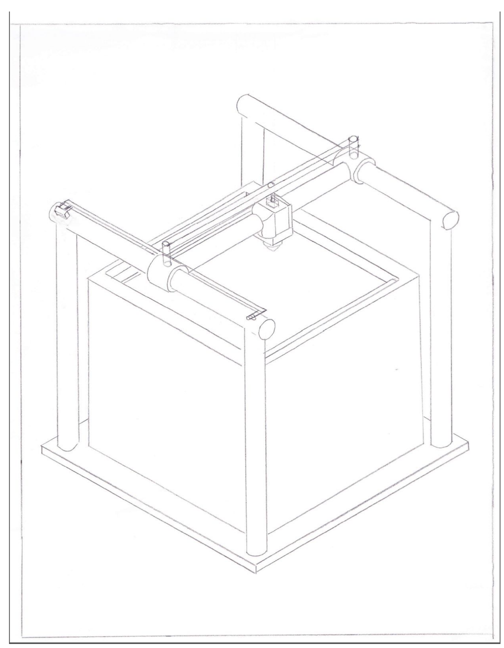

Figure 9 : isometric view

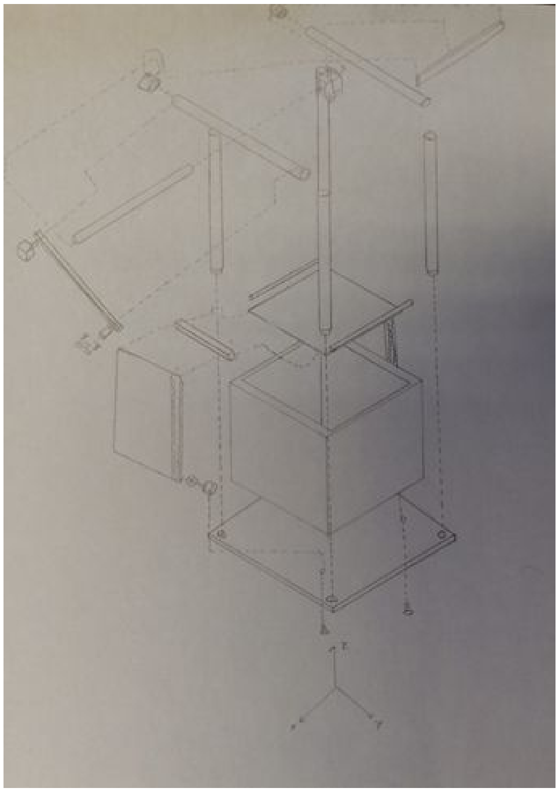

Figure 10: Assembly view

4.2.2. Motor Selection:

Our decision on the motor is based on the comparison of motor size and weight, force and accuracy. NEMA14 stepper motor is chosen for our application, and four of them are used to operate our candidate design 2. [7, 8]

- shaft diameter is 5mm
- step angle is 1.8 degree
- length of 34mm
- Average torque of 12.3N.cm ~ 13.7N.cm
- step accuracy of 5%
- weight 130g

4.2.3. Belt Selection:

	Timing Belt	Flat Belt
Accuracy	✔	
Slippage	✔	
Torque	✔	
Power Transfer Efficiency	✔	
Installation (track)	✔	
Wear		✔
cost		✔

Table 2 :Timing belt vs flat belt

The common belts used for small force applications are timing belt and flat belt. This printer uses a timing belt due to its advantages of not slipping and handling medium torque. This belt has been chosen to be 1mm thick and 5mm wide. In the case of thin belts with small surface area, the flat belt will not have enough grip to accommodate small accurate movements. Also, to implement flat belt, we will have to install tracks which will complicate the design. Therefore, the timing belt is chosen over the flat belt in our application.

4.2.4. Movement Mechanism:

To achieve movement in all the three axis, linear bearing and belt driven mechanisms were chosen to be analyzed. Linear bearings are used for sliding movement in the x and y direction while the belt mechanism is chosen for the z movement for the heated board. There will be two belts in the z movement to ensure accurate movement.

Stepper motors are used for movements in all directions as it gives small precise torque motion. First, the x direction movement is a belt system where the linear bearing is attached to the extruder body. For the movement in y direction, two linear bearings are used and driven by a motor attached on the top left bar. The insulation box is used to slow the rate of cooling of the printed part to minimize warping and increase accuracy of the printer. There are two sets of belts and motor to drive the movement in the z direction.

	Belt System	Screw System
Accuracy		✔
Ease of Replacement	✔	
Cost	✔	
Weight	✔	
Average Speed	✔	
Noise	✔	
Replacement period		✔

Table 3: Belt system vs Screw system

Two systems were considered for our mechanism, the belt and screw system. Although the screw system outperforms the belt system in lifespan (no stretch) and accuracy, belt system has many advantages in other categories. The belt is cheaper and has a higher max speed of around 120 inch/sec. Also, the efficiency is around 90% with less inertia and minimal noise during use. The screw system can generate disturbing noise when it is not lubricated well and it can also 'whimp' due to an imbalanced load. If we assume static movement and constant load, the belt will not have a backlash.

4.2.5. Design Analysis:

There are some improvements that can be done on this candidate design, the insulation box is not necessary and by removing it, we can reduce the material used to build the printer and the complexity will greatly decrease as well. Also, the two belt system used to move in the z direction are very unstable and can easily 'wobble' as there are no directors to prevent it. By having a solution to the 'wobble' effect, the quality of the printed part can be increased. Such imperfections are considered and improved below in the candidate design 3.

4.3. Candidate Design 3:

4.3.1. Motor Selection:

As the printer-head should be able to change direction at any one point within the specified printing bed, it should be able to come to sudden stops as well as accelerate suddenly to achieve a reasonable speed. In agreement with the research conducted, as the feeder needs to move in discrete steps, a input motion which is also provided in steps would make design easier. Hence a Bipolar Stepper Motor is chosen. Considering the spatial availability, a NEMA 14 motor with the following specifications is chosen.

- 200 steps per revolution (1.8 deg/step)
- Option of Rated Current: 0.8A
- Option of Rated Voltage: 4.6V
- Holding torque: 15N.cm and 9N.cm
- Shaft diameter: 5mm 0.188 inch; (3/16 inch;)
- Shaft length: 22mm
- Motor depth: 34mm
- Motor speed: 100 rpm [1]

4.3.2. Step Size:

The motor will rotate 1.8deg/step = 0.0314 radians.

According to engineering specifications, a theoretical step size of 25 microns is necessary (as this is the accuracy of the printer).

If the pitch radius of the belt = r, then s = r*0.0314rad gives the distance the feeder will move on the Y-axis per one step of the stepper motor. With the accuracy constrainment of 25 microns, the pitch radius, ‘r’ of the belt is calculated to be 0.8 mm. This is not a suitable value as belts (and gears) of this pitch would be really hard to manufacture (custom).

Therefore, we are specifying that the stepper motor will be micro stepped with 1/16 Pololu driver, in order to increase the step size to match the specifications. Now the step size can be can be calculated as follows:

Steps per one full revolution (360deg) = 200*16 = 3200 and hence, one step amounts to 0.00196 radians, and using same calculation method as before, 12.75 mm is obtained for the radius of the pitch circle. This is rounded down to 8mm to match with industry values in order to obtain standardized parts (For pulleys and sprockets). This round-off would also increase the accuracy to 15.7 microns for this system.

4.3.3. Speed:

The rotational speed of the motor is 100 rpm. This will give an overall speed of :

(15.7 microns)* (3200 steps/revolution)*(100 rpm) = 5024000 microns/min = 5.024 m/min

However this is a highly theoretical calculation based on the assumption that the printer prints a straight line in the y-direction.

4.3.4. Translating Input from the Motor:

4.3.4.1. Mechanism:

Three methods of achieving this were recognized.

1. Gear train
2. Belt driven
3. Chain driven

Comparing these three alternatives, the gear train is seen as the least attractive choice as the input and the output are spaced apart in this scenario (of varying distance), and this would require a complex gear system to achieve the same motion achieved by a simple belt or chain system. Therefore the option of using gear train is ruled out.

Main advantages a chain drive has over a belt drive are:

- Precise speed ratios can be obtained
- Longer lifespan

However, precise speed ratios are not a necessity for this specific situation as the input gear and output gear are 1:1 ratio.

Main advantages a belt drive has over a chain drive would be:

- Less noise
- Better shock absorption (less vibration and no danger of derailment)
- Lubrication is not mandatory (there are belts that do not require lubrication)

For a hobbyist audience, less noise, no lubrication are considered major advantages as they promote ease of use and safety. Furthermore, better shock absorption would lead to less vibration, which would mean better overall accuracy.

Therefore, the belt system proves to be the better choice.

4.3.4.2. The Belt/Pulley System:

4.3.4.2.1. Belts:

Looking at existing models, the following belts were recognized as the most used and preferred:

- PowerGrip GT3 belt
- HTD (High torque drive) belt
- Spectra fishing line

Out of these options it seems that the PowerGrip GT3 is a newer model by the Gates company which manufactures the HTD belt. In the opinion of the company, the GT3 outperforms the HTD in load carrying capacity as well as backlash reduction and weight. Also, the GT3 does not need lubrication which is a plus point when it comes to ease of use. The body is made of Neoprene which ‘provides protection against grime, grease, oil and moisture’ according to the manufacturer. Teeth of the belt are made of nylon for durability [2].

According to the literature, the Spectra fishing line method is a novel method that has emerged within the open source community. The idea is to use the motor to spin a spool of Spectra fishing line, which goes around a pulley and connects to the slider. The method is being praised for its smoothness in motion and the small bend radius which allows for smaller pulleys and in turn, a smaller step size. Furthermore, the Spectra Fishing line is cheaper and more available to the public [3]. However, it is worth mentioning that the use of the fishing line, for something it was not intended for, could give rise to unforeseen problems. Some users complain about the collection of dirt on the spool resulting in slippage and jamming [4].

Taking the above into consideration, it was decided that the GT3 belt should be used mainly due to the unpredictability of the Spectra fishing line method.

4.3.4.2.2. Sprockets/Pulleys:

The choice is limited in this case due to the use of GT3 belts which only match with GT2 sprockets. Hence GT2 sprockets are chosen.

4.3.4.2.3. Tensioner:

The tensioner serves the purpose of tightening the belt drive around the pulleys, thus ensuring correct contact ratio and a smoother motion. The tensioner used for this system is similar to the one used in bike chains in design. This choice was made in order to keep the design simple yet effective. The actual tensioner design includes a pulley which is mounted on top of the same bracket which holds the pulley for the belt drive with the help of a screwed shaft. Loosening the screw allows us to adjust the angle at which the belt is pressed downwards. It can be easily tightened back after required adjustment. The tensioner is really effective since the belt drive in our design does not require a large force for achieving the required tension.

4.3.4.3. Slider Mechanism:

To move the bar carrying extruder in y-direction, following mechanisms were considered:

1. Linear Bearings
2. Slider Rails
3. Track Roller Rails

Linear bearings have the following advantages over the other two [9, 10]:

- can be installed in any position without affecting loading capacity
- allow a smoother operation due to less friction

Slider rails have the following advantages [11, 12]:

- provide better friction
- have longer life span
- less prone to malfunctioning or damage
- can withstand vibrations and impacts, providing stability to the overall design
- can resist water induced corrosion and dirt

Track roller rails were not considered in the analysis since their use is limited to applications where accuracy is not a key requirement. From the above mentioned comparison, slider rails were chosen for the final design. Furthermore, the slider rails or sleeve bearings used do not require any lubrication.

4.3.5. Motor Selection for Z-Axis:

For movement in the z-axis the Nema-17 motor was used over the Nema-14 motor. This was mainly due to the additional load that the motor has to handle due to the weight of the bed and the bed frame. According to the dimensions and the material densities the total weight of the bed including the frame was approximated to be 1kg. In addition to the bed and frame, the motor must also be able to potentially lift a (200x200x200)mm of Acrylonitrile Butadiene Styrene (ABS plastic of density 1040 kg/ m^3) block [13]. The mass of the block would be, 0.008 m^3 x 1040 kg/ m^3 = 8.32 kg. Therefore, the two motors facilitating motion in the z direction would have to handle a total axial force of (1 kg + 8.32kg) x 9.81m/ s^2 = 91.43 N. The axial force generated by a lead screw is governed by the equation:

Force = $\frac{2\pi * Torque * Efficiency}{Lead}$ [14]

After the calculations, the required torque is found to be 0.14N.m. Therefore the Nema 17 motor is the ideal choice as it produced a maximum torque of 0.4N.m. Although the Nema 17 exceeds our required torque by over 100%, it is a safer option to have excess of torque which may be varied by varying the power input to the motor rather than having insufficient power which would delay the motion of the printer bed in the z-direction, which would lead to inaccuracies in the modelled part.

The threaded rod (Tr8*8) [15] was coupled to the motor using a Aluminum Flexible Shaft CHK0201 coupler as seen in Figure 11 [16]. This particular coupler was chosen as it is capable of transmitting the torque provided by the motor with minimal likelihood of failure and is highly standardised which minimizes cost.

Figure 11 (CHK0201 coupler)

The *8 indicates that for one unit turn (i.e. 360 degrees), the bed would travel 8mm in the axial direction. The nema stepper motor has 3200 increments per one revolution. Therefore on increment would be equivalent to 0.1125 degrees. So the printer bed would have an accuracy of 0.0025mm per unit increment of the motor.

During operation if the threaded rod is meshed with a conventional nut , there is a possibility of backlash. This Backlash would lead to a number of problems such as: inaccuracies during the reversal of the threaded rods direction, vibration of the nut relative to the threaded rod and premature wear of the meshing threads between the rod and nut.

To mitigate this issue, we used a anti-backlash nut as seen in Figure 11. This is a highly standardized part, therefore in regards to cost, it will only cost $10.00 per unit [17]. In addition to cost, the anti-backlash nut has a split nut mechanism that ensures that the contact ratio between the threaded rod and the nut is large enough throughout the operation of the 3D printer to prevent the above mentioned issues [18].

Figure 12: anti-backlash

4.3.6. Heated Bed:

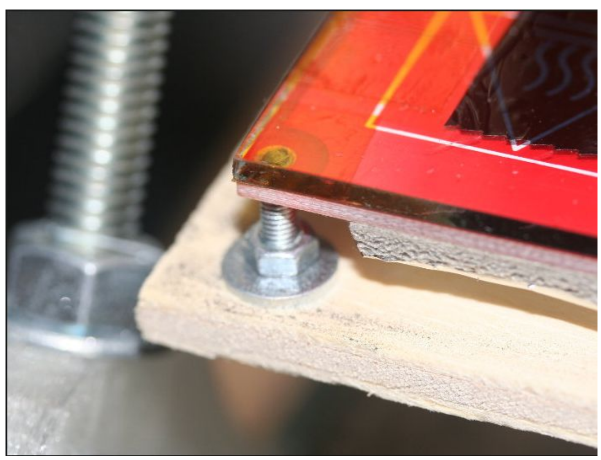

Figure 13: Heated Bed

A heated bed is needed to improve the quality of the printed material, especially to prevent warping. Therefore, the bed should provide heat and adhesives. The heater prevents warping and the adhesive allows the part to be stable during printing; otherwise, the part will stick to the extruder and move with the extruder. [19]

There are three layers to the heated bed, the top layer will be borosilicate glass 2mm thick. It will also act as the adhesive layer for the printed part [19]. The middle layer will be PCB that is 200mm*200mm with 1mm in thickness and it will provide heat. PCB is commonly used in printer beds as they are inexpensive, great performance and easy to replace.[19] The bottom area will be cork of 2mm thickness as it has excellent thermal performance and acts as an insulator and helps the PCB heat up faster. Therefore, the total thickness of the bed is 5 mm and the cost is around $45.[20, 21, 22]

4.3.7. Feeder/Extruder Mechanism:

4.3.7.1. Feeding the Coil:

The mechanism that feeds the material to the hot end of the extruder is always in constant motion and so we decided on using a mechanism with minimum volume, complication and weight. Since we do not need high torque, NEMA 14 was chosen to provide the rotational motion to the mechanism.

A gear system is implemented to achieve the desired motion. The shaft of the motor is coupled to a 10 tooth gear of module 1.25 which is inturn meshed with a 43 tooth gear of the same module. Figure 3.3.1 shown below depicts this mechanism.

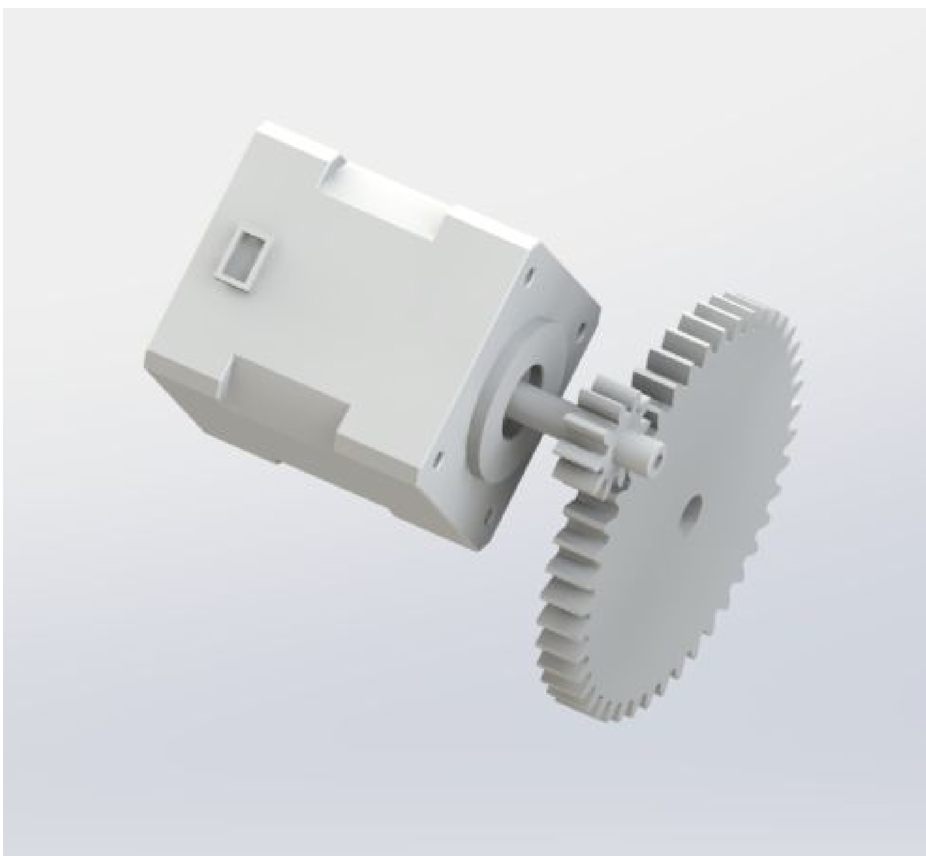

Figure 14 : Motor connected to the gear train

The 43 tooth gear is fitted with a long shaft which is used to drive the material to the extruder. The other end of the shaft goes through a housing where this feeding mechanism takes place. The housing is an open rectangular box. To provide frictionless movement, ball bearings are press fit at the areas where the shaft goes through the walls of the housing. Inside the housing, a hobbed wheel is fit with ball bearings which is close to the shaft of the gear. The material wire goes between these two and as the shaft rotates, the wheel rotates and the material is fed downwards. The figure below shows the assembly of this mechanism:

Figure 15 : Assembly of the housing

Before it was finalized to use the hobbed wheel, we considered other options like a groove cut out on a surface through which the material is fed or a wheel without being hobbed. In case of a groove cut on a surface, there would be too much friction which might eventually make the shaft to just slip over the surface and the material will not be fed to the extruder. As for a wheel, the shaft might still slip because of too less of a friction being applied by the wheel. If the same wheel is hobbed, it will provide the needed friction for the material to move to the hot end of the extruder.

At the hot end of the extruder, Nichrome wire is wound which is connected to a heater. The required heat is produced by this wire. The final melted material is extruded out of a 25 microns nozzle since the accuracy of the printer was decided to be 25 microns earlier.

4.3.7.2. Material Selection:

A considerable amount of heat is produced in the process of printing and since metal conducts more heat than polymers do and gets heated quickly, we decided to use plastic gears rather than metal gears. Though there is an advantage of controlling the heat conductance by using insulated material, plastic for gears, there is also a disadvantage. Metal can handle high torque and force whereas plastic can't. Since in this situation, low torque and low force is produced, we decided to use plastic for its insulation properties.

Further in plastic, we narrowed down the options to ABS (Acrylonitrile butadiene styrene)[23] plastic and PLA (poly lactic acid)[24] plastic. The following table provides the information on both the plastics:

Table 4: ABS vs PLA

	ABS	**PLA**
Melting Point	230^0 C	150^0 - 160^0 C
Load Capacity	Medium	High

As we can see, PLA has low melting point but it can handle high force and torque, usually 5-6 times that of what ABS can handle. Even though ABS has medium handling capacity, we decided to use this material to make the feeder components because of its high melting point.

Since ABS or PLA can be used as printing material, the produced heat has wide range. Also, PLA starts warping around 55^0 C which is not desirable when the temperature might go higher.

At the hot end of the extruder, huge amounts of heat is produced to melt the plastic and so use of a higher heat resistant material is essential. PTFE (Polytetrafluoroethhylene) also known as Teflon[25] was considered for this purpose. Teflon has a melting point temperature of 335^0 C and is easily available. Hence Teflon is used at the hot end of the extruder.

4.3.7.3. Heat Management:

Even with all the precautions taken to manage heat produced during the process of feeding and extruding, it is safe to consider adding few precautions. In our case, we decided to add a heat sink around the Teflon cylinder at the hot end of the extruder. Heat sinks are made of material with high thermal conducting properties and so the heat produced is quickly conducted to surrounding air [26]. This reduces the heat transferred to the feeding system.

Two materials were considered for this purpose, aluminium alloys and copper. Since aluminium alloys is a widely used material and is 2-3 times less expensive than copper, the material for the heat sink is chosen to be aluminium alloy. The picture below shows the heat sink we designed.

Figure 16 : Heatsink used around the hot end of the extruder

4.3.7.4. Assembly:

After putting together the motor, gears, housing, extruder, and heatsink, three different brackets are used to attach the entire feeder/extruder to the top section of the printer. Two L-shaped brackets are used for motor and housing each to be screwed on to a C-shaped bracket. The other side of this bracket is screwed to the top section of the printer. The following picture shows how the feeder/extruder look like after being assembled together and to the L-shaped brackets:

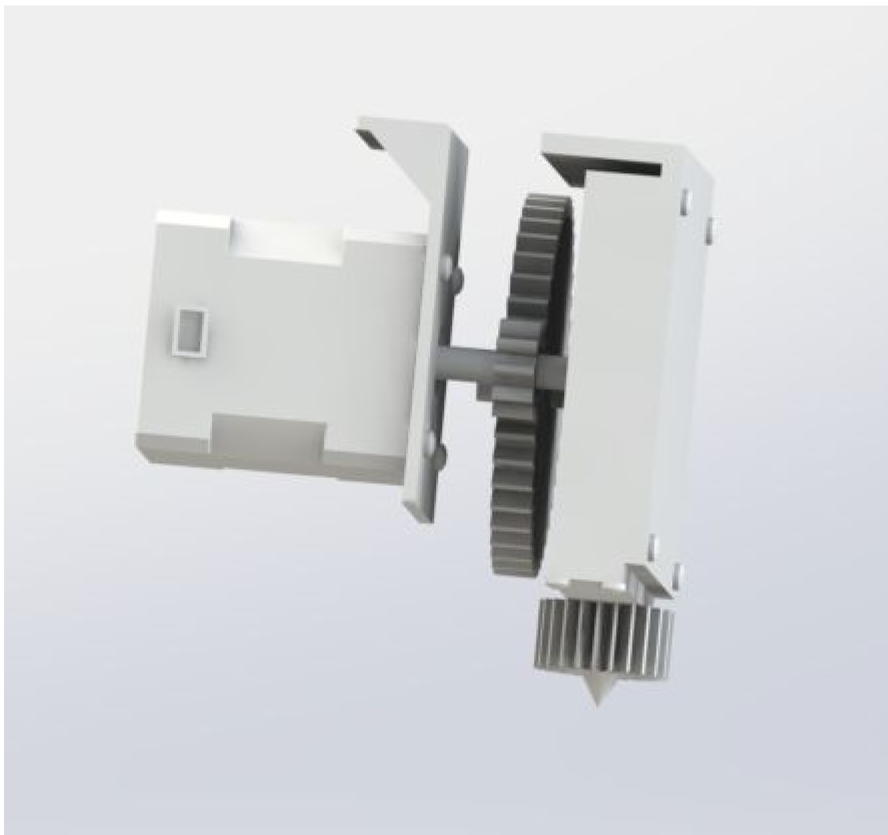

Figure 17 : Feeder/Extruder

4.3.8. Frame:

The frame is designed to have a higher aesthetic appeal than the products in the market. With that being said, the most important function of the frame would be to provide structural stability to the the printer and its components.

4.3.8.1. Base:

the base is constructed out of wood (the user can pick depending on the look/finish he or she wants). Due to its thermal insulative properties, wood will provide a safe hand rest for the user. The wood finish is also meant to give the workplace a natural look, instead of the industrial look that printers on the market today give. Production of the part would not be expensive as shaping wood is relatively inexpensive. Furthermore this reduces the environmental impact of the printer and ease of disposal as well.

A hexagonal shape is used as this allows for the four support pillars and the two threaded rods to be positioned to provide improved stability, by restricting motion in six points. Furthermore it is a basic shape which is easy to machine/produce.

Also, the printer base can be used as a writing top if the use is space restricted, by raising the mid-section.

4.3.8.2. Middle:

Material selection for the bed was discussed in detail in section (4.3.6).

The mid section of the printer will be supported by the threaded rods (connected by the anti-backlash screws to the bed frame). The four support will pass through the middle layer, connected by linear bearings (bushings) which allow for sliding along the z-axis. This will stabilize the printing bed considerably as there are six points of contact in this plane (theoretically speaking, only three points are needed to define a plane, considering the weight of the part to be printed and the bending which might occur, six points will provide a more planar surface).

A rectangular ledge and window is cut out from this section as shown in the CAD model to place the bed and to place necessary heating apparatus (and circuitry) underneath the bed respectively. This allows for approximately 8 cm spacing between the printer bed and the base at the lowest position of the bed for the placement of circuitry.

4.3.8.3. Top:

The top section of the printer consists of two pentagonal plates (wooden) connected together by two cylindrical rods and the slider rail component as shown in figure 25.

The weight of the whole top portion will be supported by the four pillars upon which the top will sit on (extruded cuts are made into the plate to make a secure fit). this allows for easy assembly of the top from the bottom which would help in removal of scrap material, cleaning and troubleshooting. The threaded rods do not come into contact with the top at all, and this allows them to spin freely (without added friction) while moving the bed in the Z-axis.

The motor mounts, and slider rails, and pulley and tensioner mounts are connected to the pentagonal plates by means of screws. Placement of motors was chosen to be as spatially conservative as possible, and thereby provide and increased printing space. This allows for, approximately, a printing area of 200mm x 200mm.

Overall, the frame allows for easy assembly (by minimizing the number of screws and parts), and for portability (i.e repositioning of the printer without completely disassembling) as well as structural stability and aesthetic appeal.

4.3.9. Engineering Drawings:

Drawings of the final design are shown here.

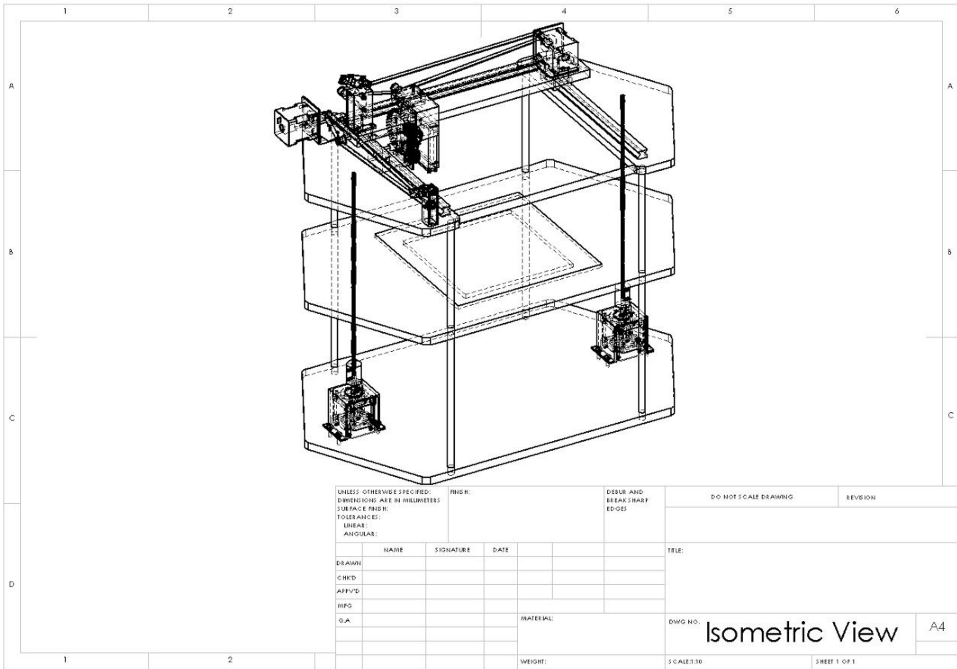

Figure 18: Isometric view of candidate design 3

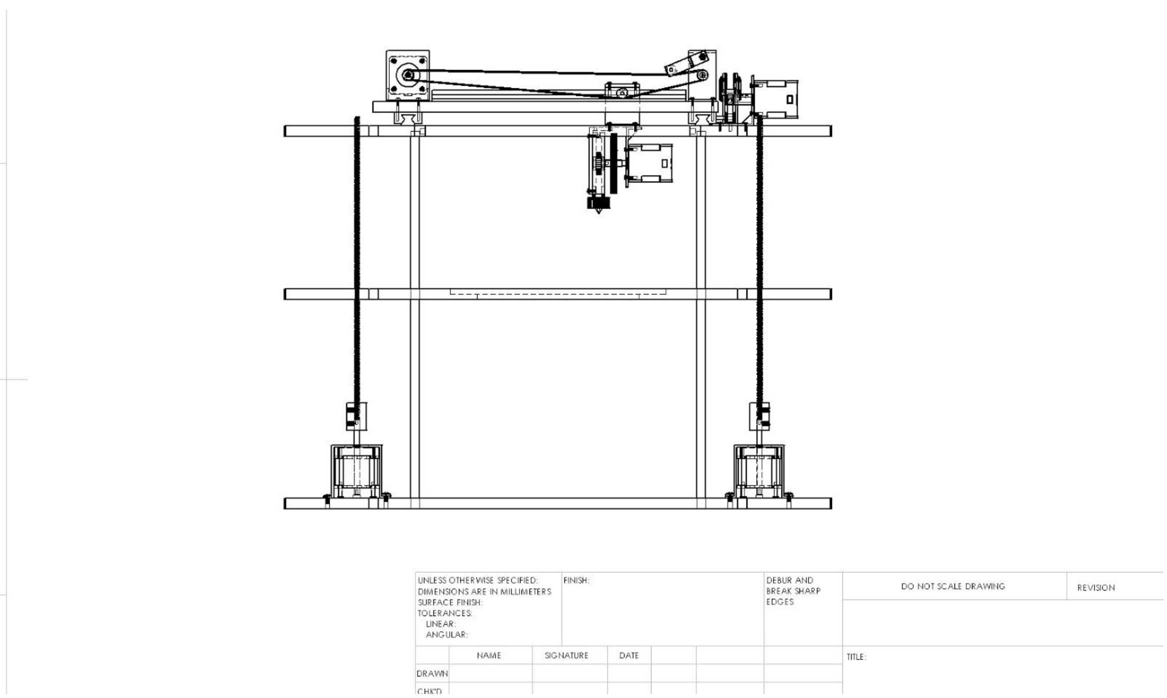

Figure 19 : Front view of candidate design 3

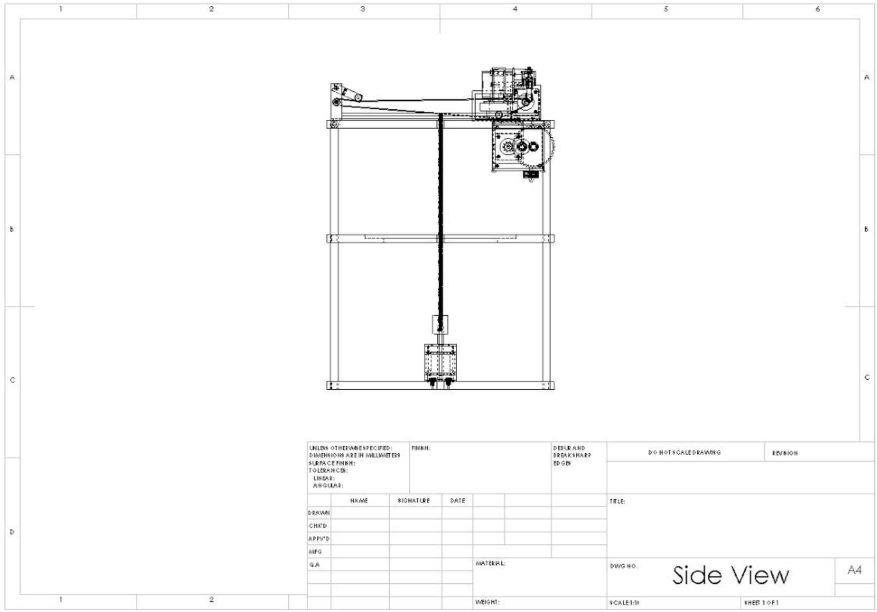

Figure 20: Side view of candidate design 3

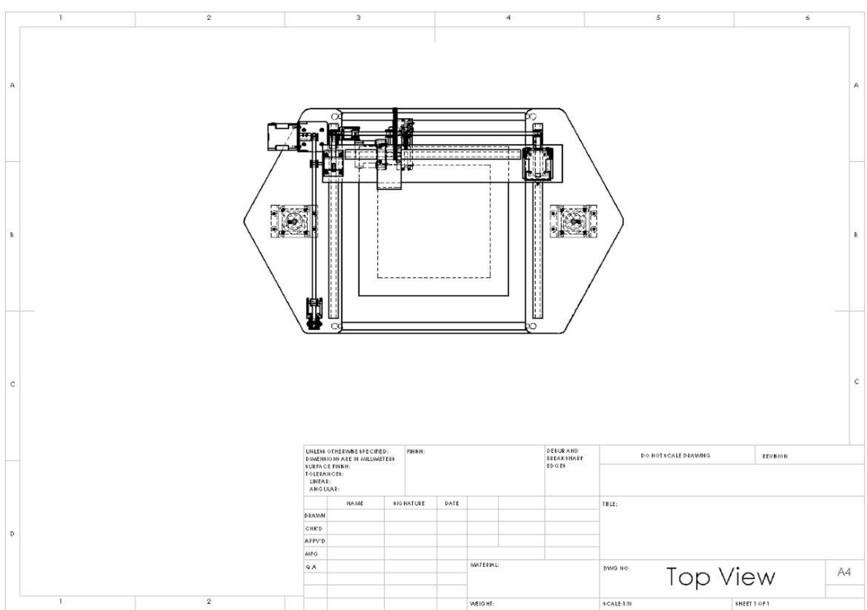

Figure 21: Top view of candidate design 3

The completed printer renderings:

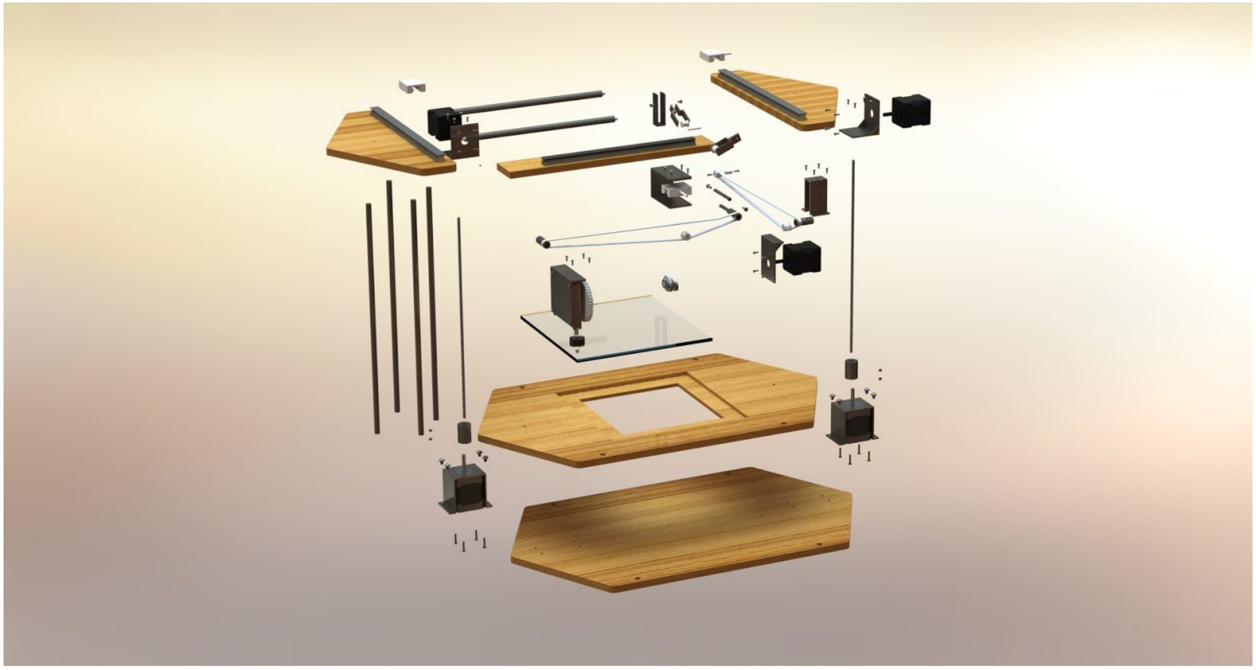

Figure 22: Assembly view of final design

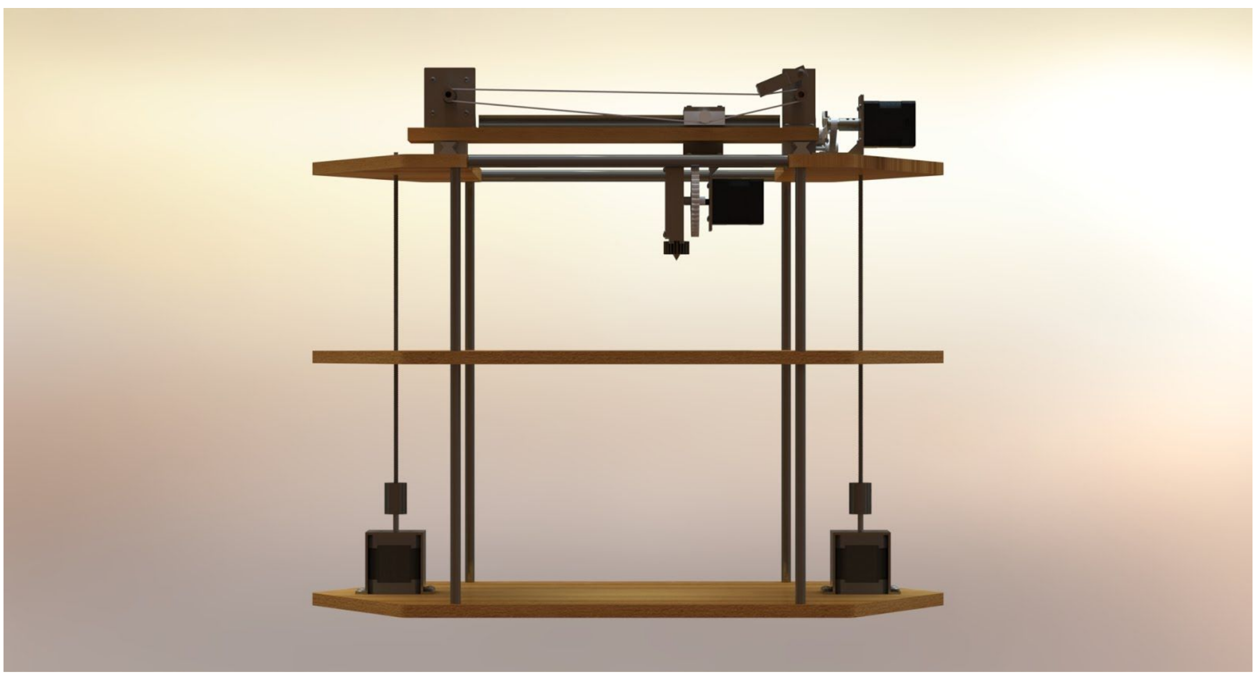

Figure 23: Front view of final design

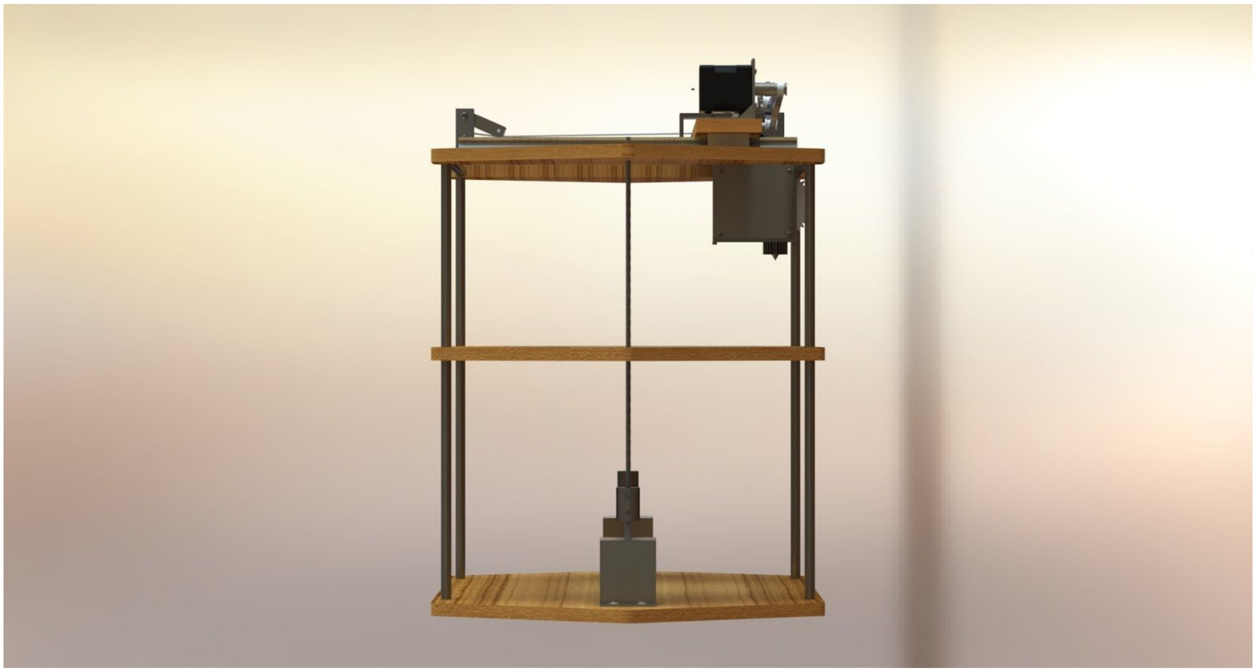

Figure 24: Side view of final design

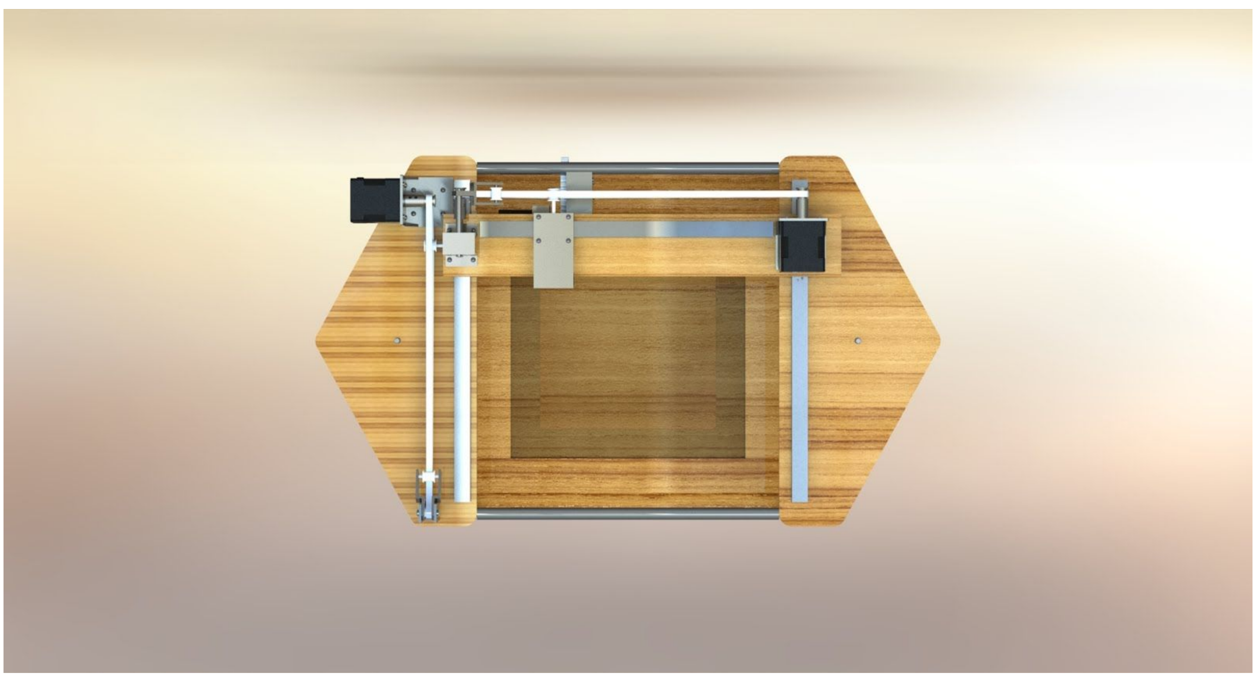

Figure 25: Top view of final design

Figure 26: Isometric view of final design

5. Cost Analysis of Final Design

Table 5: Cost analysis of final design

Component	Price ($)	Where
2 x NEMA17 Motors with threaded rods (Z-axis)	72.00	ROBOTDIGG: http://www.robotdigg.com/product/8/Threaded-Rod-NEMA17,-280mm-Tr8*8mm-Acme-Leadscrew
3 x NEMA14 Motors (X,Y and extruder)	20.40	ROBOTDIGG: http://www.robotdigg.com/product/28/NEMA14-34mm-0.8A-or-1.25A-stepper-motor
2 x Anti-backlash screw	20.00	ROBOTDIGG: http://www.robotdigg.com/p

		roduct/18/Anti-backlash-Nut-for-Tr8*8-Leadscrew
2 x GT2 Sprockets	4.00	ROBOTDIGG: http://www.robotdigg.com/product/9/GT2-Pulley-20-Teeth-5mm-Bore
2 x GT2 pulleys	4.00	ROBOTDIGG: http://www.robotdigg.com/product/59/Rostock-16-Teeth-5mm-Bore-GT2-Pulley
2 x GT3 Belts (1 roll)	2.00	ROBOTDIGG: http://www.robotdigg.com/product/10/Open-Ended-6mm-Width-GT2-Belt
Heated Bed	45.00	http://www.ebay.com/sch/i.html?_trksid=p2053587.m570.l1311.R4.TR9.TRC2.A0.H0.X3d+printer+he&_nkw=3d+printer+heated+bed&_sacat=0&_from=R40 http://www.ebay.com/sch/i.html?_odkw=3d+printer+heated+bed+borosilicate+glass&_osacat=0&_from=R40&_trksid=p2045573.m570.l1313.TR0.TRC0.H0.X3d+printer+heated+bed+borosilicate+glass+-set&_nkw=3d+printer+heated+bed+borosilicate+glass+-set&_sacat=0
Heat Sink	5.99	http://www.ebay.com/itm/1pc-5W-Watt-LED-Aluminium-Heatsink-Round-/250863138

		134?pt=LH_DefaultDomain_0&hash=item3a689bb556
Gears	1.54	http://www.ebay.com/itm/11-Styles-Plastic-Gears-All-The-Module-0-5-Robot-Part-for-DIY-/121147929885?pt=LH_DefaultDomain_0&hash=item1c34fab51d
Total	317.73	

**Note: Prices of the components are estimated using internet based market values. Therefore it is possible that prices may vary based on the location as well as the seller.*

6. References:

[1] “3ders” Internet: http://www.3ders.org/3d-printer/3d-printer-price.html [Accessed: 13 March, 2014]

[2] 3Ders, "3ders - price compare 3D printing materials," 2014. [Online]. Available: http://www.3ders.org/pricecompare/?o=Price%20per%20kg. [Accessed 2014].

[3] “3d Printed Instruments” Internet: http://3dprintedinstruments.wikidot.com/methods. [Accessed: 12 March, 2014]

[4] “3ders” Internet: http://www.3ders.org/pricecompare/3dprinters/ [Accessed: 13 March, 2014]

[5] “National Institute on Deafness and Other Communication Disorders”, “Common Sounds” Internet: [http://hlaa-wi.org/yahoo_site_admin/assets/docs/Noise_Induced_Hearing_Loss_-_CommonSounds__Noise_Levels_NIDCD.170133737.pdf] [Accessed: 14 March, 2014]

[6] “Vias” Internet: http://www.vias.org/comp_geometry/img/math_cylindric_coords.png [Accessed: 20 March, 2014]

[7][NEMA 14 stepper motor, [online] 2014,. http://reprap.org/wiki/NEMA_14_Stepper_motor, (Accessed: 15th April 2014)]

[8][Fidgets NEMA 14 stepper motor, [online] 2012,. http://www.phidgets.com/products.php?product_id=3301(Accessed: 15th April 2014)]

[9] robotdigg, stepper motor NEMA 14 [Online] http://www.robotdigg.com/product/28/NEMA14-34mm-0.8A-or-1.25A-stepper-motor [Accessed on 2nd April 2014]

[10] Gates, GT3 belts [Online] http://www.gates.com/products/industrial/industrial-belts/synchronous-belts/powergrip-gt3-belts [Accessed on 2nd April 2014]

[11] Reprap, Fishing line [Online] http://reprap.org/wiki/RepRap_Options#Belts_and_Pulleys [Accessed on 2nd April 2014]

[12] Reprap, user Owen’s dirt problem [Online] http://forums.reprap.org/read.php?178,206458,249196 [Accessed on 2nd April 2014]

[13] ABS Plastic Data,[Online] 2010, http://teststandard.com/data_sheets/ABS_Data_sheet.,pdf, (Accessed: 20th March 2014).

[14] Lead Screws, Manufacturer Repersentative, [Online] 2006, http://www.smallmotors.com/html/lead_screws.html (Accessed: 20th March 2014).

[15]Threaded Rod,Robotdigg, [Online] 2010,.http://www.robotdigg.com/product/8/Threaded-Rod-NEMA17,-280mm-Tr8*8mm-Acme-Leadscrew, (Accessed: 20th March 2014).

[16] DHgate, Couple, [Online] 2012, http://www.dhgate.com/product/aluminium-cnc-stepper-motor-flexible-shaft/157062409.html, (Accessed: 20th March 2014).

[17] Anti-backlash Nut, Robotdigg, 2010, http://www.robotdigg.com/product/18/Anti-backlash-Nut-for-Tr8*8-Leadscrew, (Accessed: 20th March 2014).

[18] KHD Series, Haydon, 2009, http://www.haydonkerk.com/LinearActuatorProducts/LeadScrewsAndNuts/Nuts/KHDSeriesNuts/tabid/145/Default.aspx, (Accessed: 1st April 2014).

[19] [Boots Industries [Online] http://bootsindustries.com/portfolio-item/heat-bed-3d-printing/,. (Accessed 15th April 2014)]

[20][RepRap, Heatbed Thermal Insulator 200 [Online] http://reprap.me/iso200.html (Accessed 15th April 2014)]

[21][ebay, heated bed boroscilicate glass set [Online] http://www.ebay.com/sch/i.html?_odkw=3d+printer+heated+bed+borosilicate+glass&_osacat=0&_from=R40&_trksid=p2045573.m570.l1313.TR0.TRC0.H0.X3d+printer+heated+bed+borosilicate+glass+-set&_nkw=3d+printer+heated+bed+borosilicate+glass+-set&_sacat=0 (Accessed 5th April 2014)]

[22][ebay, 3d printer heated bed [Online] http://www.ebay.com/sch/i.html?_trksid=p2053587.m570.l1311.R4.TR9.TRC2.A0.H0.X3d+printer+he&_nkw=3d+printer+heated+bed&_sacat=0&_from=R40 (Accessed 10th April 2014)]

[23] “RepRap” Internet: http://reprap.org/wiki/ABS [Accessed: 2 April, 2014]

[24] “Wikipedia” Internet: http://en.wikipedia.org/wiki/Polylactic_acid [Accessed: 2 April, 2014]

[25] “Boedecker” Internet: http://www.boedeker.com/teflon_p.htm [Accessed: 2 April, 2014]

[26] “ABL Heatsinks” Internet: http://www.abl-heatsinks.co.uk/heatsink/heatsink-selection-material.htm [Accessed: 2 April, 2014]

[27] “GrabCAD”, “The NNEMA 14 Stepper motor” Internet: https://grabcad.com/library/nema-14-stepper-motor [Accessed: 15 March, 2014]

[28] “GrabCAD”, “The NEMA 17 Stepper motor” https://grabcad.com/library/nema-17-stepper-motor-1 [Accessed: 15 March, 2014]

[29] “GrabCAD”, “ACME threaded rods” https://grabcad.com/library/generic-metric-threaded-rod [Accessed: 15 March, 2014]