



ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)  
GRADO EN INGENIERÍA ELECTROMECÁNICA  
Especialidad Mecánica

## **LARGE FORMAT 3D PRINTER**

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Director: Daniel Codd

Madrid  
June 2018



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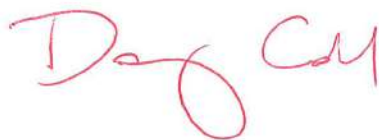


Authorized the delivery of the project

**THE PROJECT DIRECTOR**

Signed: Daniel Codd

Date:



12 - July - 2018





# IMPRESORA 3D XXL

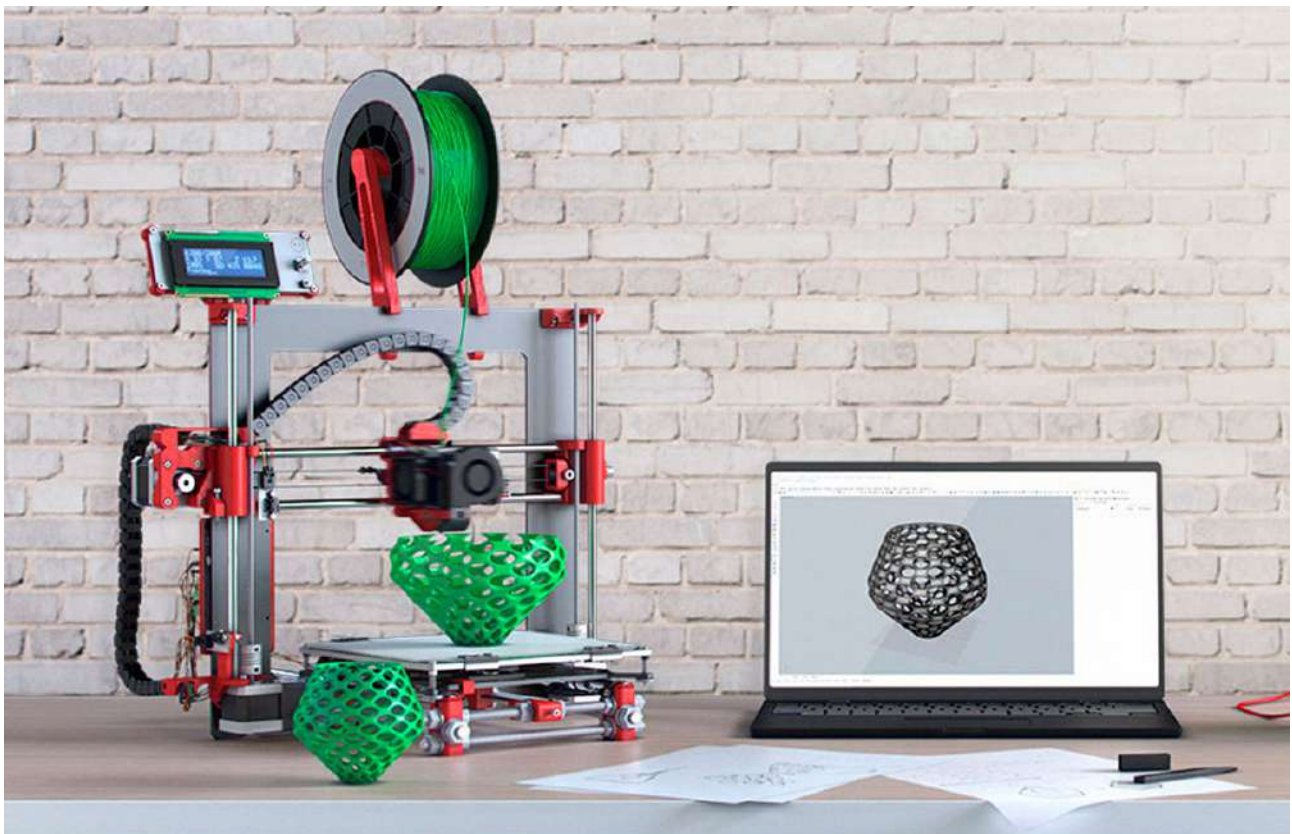
**Autor: Ruiz Ortega, Pablo**

Directores: Codd, Daniel

Entidad Colaboradora: University of San Diego

## RESUMEN DEL PROYECTO

El uso de las impresoras 3D es cada vez mayor y podemos confirmar a día de hoy que es un método muy reconocido y usado tanto por empresas como para uso personal a la hora de modelar, diseñar o incluso crear piezas que no requieren una alta resistencia. El mundo de la impresión 3D no ha parado de crecer desde que éste método de diseño apareció, y actualmente sigue desarrollando nuevos funcionamientos y usos, por ello aparece la variante de impresión 3D a gran escala.



El mayor problema de las impresoras 3D de grandes dimensiones es el coste. El precio de estas invenciones es muy elevado en comparación con las impresoras 3D de tamaño normal que hoy en día se usan tanto para uso profesional como personal. En el mercado actual no existe una impresora 3D con un volumen de impresión de 0.5x0.5x0.5m por menos de \$10.000. Esto ha causado que las impresoras grandes se usen solamente para uso profesional y no individual. Por ello es claro el

espacio que deja el mercado para una impresora de grandes dimensiones y coste reducido, y en este proyecto el objetivo es conseguir bajar el coste de dicha máquina para así conseguir un mayor uso. Para superar este problema se usarán materiales de bajo coste para la estructura exterior, se ahorrará en componentes electrónicos y se estudiarán a fondo todas las posibles opciones de compras a la hora de usar el presupuesto. Esto no quiere decir que la impresora vaya a ser de mala calidad, por lo contrario, quiere decir que se usara el presupuesto de manera extremadamente cuidadosa y no se gastará nada en partes que pueden funcionar correctamente con materiales más baratos. La mayor parte del presupuesto se dedicará a importar las partes más fundamentales de la máquina como los componentes de deslizamiento para la movilidad en los ejes X Y Z o el aparato de extrusión elegido.

Las impresoras grandes presentan numerosos retos excluyendo su elevado coste de construcción como es el tiempo de impresión. Al imprimir piezas de gran tamaño el proceso es extremadamente largo pudiendo llegar a impresiones de hasta mas de 30 horas de duración, pero este problema se puede resolver con numerosas opciones que se estudian a lo largo de este proyecto, como por ejemplo aumentar el flujo de plástico y así poder trabajar a mayores velocidades sacrificando un poco de calidad de acabado en casos de impresiones de muy gran tamaño.

Dado que el mercado de impresoras 3D de gran escala no está muy explotado, es un mundo con muchas posibilidades a estudiar y desarrollar y por ello uno de los motivos por los que se realizará este proyecto es el de descubrir hasta qué punto las empresas que fabrican este tipo de máquinas están multiplicando su precio para beneficio propio, y realmente cuánto presupuesto hace falta para conseguir grandes impresiones de alta calidad.





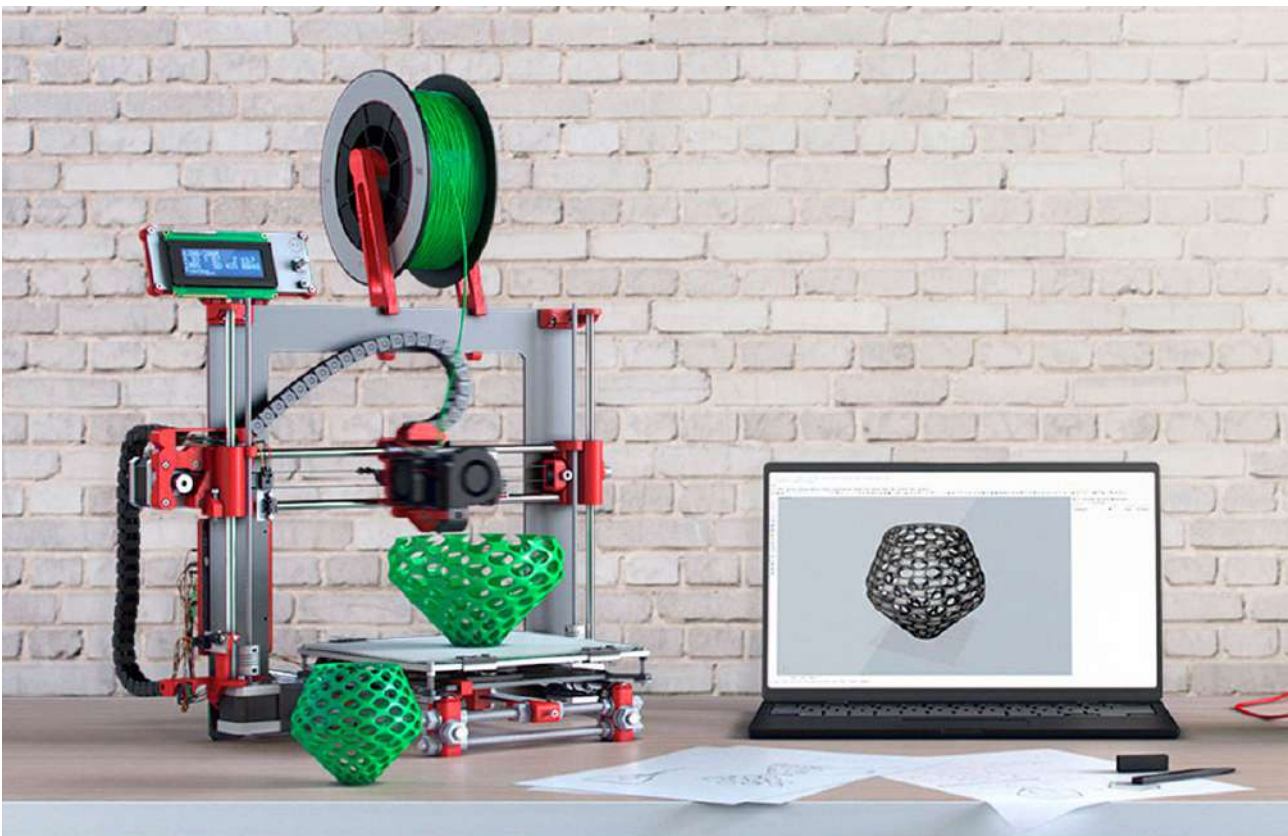
# LARGE FORMAT 3D PRINTER

**Author: Ruiz Ortega, Pablo**

Directors: Codd, Daniel

Collaborating Entity: University of San Diego

The use of 3D printers is growing every day and nowadays it is a very fast and known way for businesses or individual people to design and create models or even build parts that will be used for jobs that do not require high strength on the material. The 3D printing world has not stopped to develop since this new method of designing appeared and now it is still changing and using new ways of functioning or new possible uses you can use it for. For that the large scaled 3D printing became one of the big challenges and uses that have appeared.



The biggest issue with large scale 3D printers is the Price. These inventions have a very high cost compared to the normal sized printer that people use every day professionally or individually. The price of a XXL printer on the actual market does not go below \$10.000. For this, now the big printers are only used professionally in designing businesses that want to model parts, and leaves no space for personal use since the price is too high for that. This leaves a big gap in the market for a new low cost printer that can print big parts and is not as expensive as the rest. For that, the main goal is to create a large scale 3D printer using low cost materials.

To take care of this issue, the printer will be designed using Solid Works and then use low cost materials in every subsystem that won't affect the quality of the prints. Every possibility will be studied and reconsidered trying to find the cheapest option without forgetting about the high quality that we are looking for. Most of our budget will be used to take care of the most important parts of our printer like our linear motion system for the X Y Z movement or the extruder.

The large 3D printers have many more challenges that have to be considered when designing it such as the printing times. When printing pieces that are this big, the printer could be working for over 30 hours, but this issue can be solved with many different answers that this project studies and talks about like rising the flow of plastic through the extruder so that the print can reach higher speeds risking a bit of its quality.

Because the market has not yet explored all the possibilities that a large scaled 3D printer can offer, there is a lot of development that this project will go through trying to find out if it is true that it costs almost \$10.000 to build this machine or if it is the companies that are making its Price way higher because of the lack of printers on sale.



THE PROJECT CONTAINS THE FOLLOWING:

ABSTRACT

LIST OF FIGURES AND TABLES

1. CONTEXT
2. PROBLEM DEFINITION
3. DESIGN SPECIFICATIONS
4. DESIGN ANALYSIS AND RESULTS
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## **ABSTRACT:**

This document describes my work done in the subject Senior Design Project in the University of San Diego, with the help of 3 teammates and our mentor Daniel Codd, who has studied MIT and Stanford and has taught me a lot of useful things throughout this year that have been a key factor for the development of the project.

The 3D printer was built using the budget that the university gave to the project and also using all the different laboratories that the university has, including lathe machines, milling machines and forging processes. This helped to keep its cost as low as possible since we had all the tools we needed to use. It has to be said that to use those tools there is a safety procedure in which you have to pass a test and prove that you are able to use these machines with the care and respect that you should.

The objective was to make it cost less than \$2.000 without losing quality or speed on the printer, and after a year of work, the printer has achieved all the goals that were set.





# 1. CONTEXT



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## 1.1 BACKGROUND OF NEED

The target user for this printer is any person or company that needs a prototype or any other object 3D printed. The printer will specialize in large format objects because the majority of the printers on the market today are desktop size. The large format will provide a competitive advantage due to many companies only offering services for small prints. Often times companies have a new product or idea that they need visualized but do not want to pay the price of injection molding, which could cost \$30k+. Another downside of injection molding is that it is almost impossible to make changes or alterations without creating a whole new mold. 3d printing provides a cheaper alternative that can provide customers with a prototyping platform that can be tweaked easily. Printing large objects today can be ridiculously expensive, costing thousands of dollars. Building a cheap printer in house can be a cheaper alternative than buying a \$25k+ printer. If the printer stirs up enough interest in purchasing, the printer could certainly be sold as a whole or kit. Most 3d printers on the market are desktop sized and designed to make little trinkets and gadgets. This leaves a lack of large 3d printers and companies that produce large 3D printed parts. This is where the proposed printer design will come into play and fulfill the user need.

Figure 1 below shows a printer with a similar sized printing bed currently on sale for \$14,000 dollars. As you can see by the picture, many of the materials, such as aluminum extrusions and sheet metal would work great on the proposed design due its cheap, but effective nature. Another design feature that would work great with the proposed design is to make the bed move in the Z axis rather than the extruder move in the Z. This makes for more accurate prints and allows the extruder to move faster which will decrease print time.

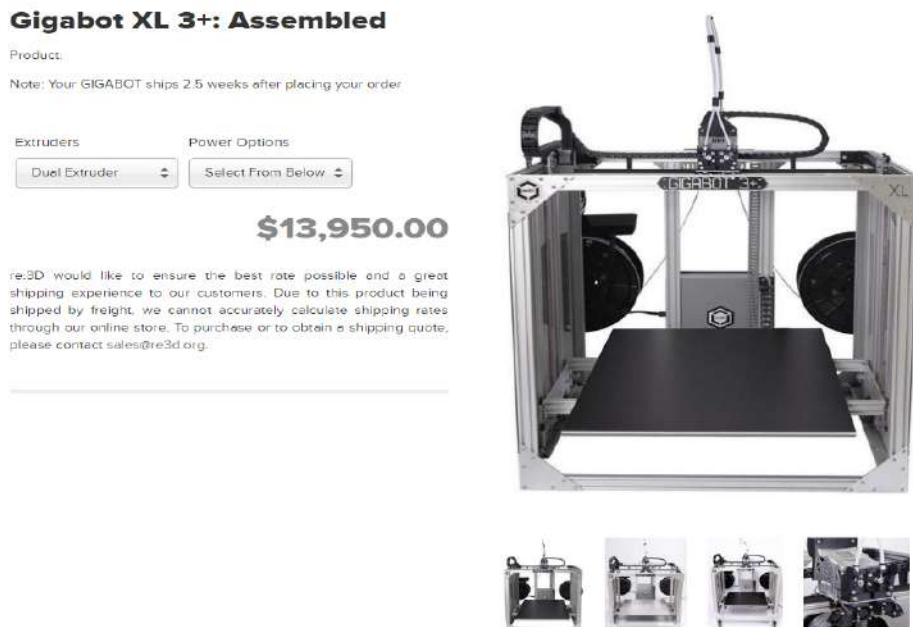


Figure 1: Gigabot XL 3+ 3D printer of similar size to Senior Design constraints.

## **1.2 CUSTOMER NEED STATEMENT**

Currently, there is no affordable way to get a large 3D part printed. The companies that exist charge up to thousands of dollars for one large part. On the contrary, if a company was looking to purchase a large format 3D printer for themselves, they are looking at a cost of up to \$30k. Companies and freelance designers are now able to see their ideas come to life within hours using 3D printers. However, there is still a size constraint, and large scaled prototypes are not feasible for conventional rapid prototyping machines. There exists the need for an effective, accurate, fast, and low cost large scale 3D printer that engineering companies and freelance designers can utilize.

3D printers started printing small parts that were never used to function as the final piece but to design and have a similar prototype in hand for a better look at what the final product would look like, but now the quality of this process has improved so much that companies can start to use these printers for their own particular use without it being a simple prototype. With an affordable big printer, the possibilities of a plastic part being used as the final product would increase and people would lose their fear on the typical expensive 3D printer.

For that this project tries to prove that a printer is not as expensive as some companies sell it for, and will decrease the cost in very part possible in order to achieve a total cost under \$2000 and deny every other company that sells these machines for a much higher price without really having a reason to do.

## **1.3 LITERATURE REVIEW**

### **1.3.1 PRIOR WORK**

3D printing has only become more popular over the years. New technologies and popularity has increased the units sold each year. Many of these are smaller desktop 3D printers sold to individuals, hobbyists, and businesses around the world. Not every one of these individuals or businesses is looking for a large scaled 3D printer, but many of them have not had an opportunity to buy a lower cost one because there are few out there. It is not farfetched to believe that the increase in popularity for smaller 3D printers will translate into large scale printers. Figure 2 shows the units sold per year and it is clear to see there is a large market for 3D printers and it is growing exponentially. This figure is another huge reason to think that the investment of time on this particular project is pointing at the right direction.

There are many large scale and desktop 3D printers on the market today. Figures 3 through 10 show various examples of these products. We are attempting to create a large scale 3D printer for a lower cost than what can be found today. Many large scale 3D printers can cost tens of thousands of dollars.



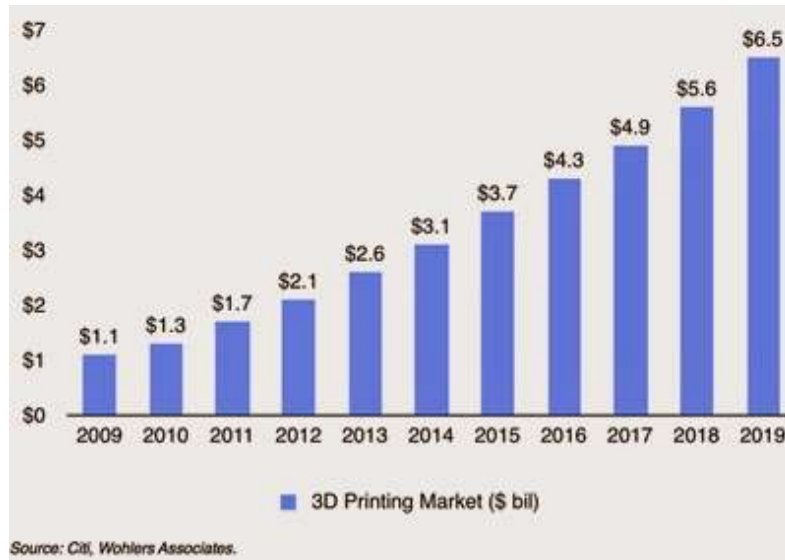


Figure 2: 3D Printing Market over time (Stipek)

The Gigabot 3D printer for \$12,000 (Figure 3), BigRep 3D printer for \$39,000 (Figure 6), and some lower cost alternatives in the \$4000-\$10,000 range. However, a man made a 3D printer with print dimensions of 300x300x695-millimeters and claims it cost him only \$1000 (Figure 9). This shows that even though many large scaled 3D printers have high costs it is possible to cut that down.

Most 3D printers sold to individual consumers are desktop 3D printers such as Makerbots and Ultimakers. The problem of making a large 3D printer is hard to solve because of print times, building mechanics, and materials. Print times increase cubically as parts increase in size. This is because an increase in volume is an increase in length, width, and height. This means that part times increase leading to more expensive parts since time is valuable. Building mechanics is also an obstacle. As gantries, carriages, and print beds increase in size so does their weight. This can lead to bowing and bending in various parts of a printer. This can be solved by increasing the strength of the 3D printer parts, which in turn can increase the cost of the printer and/or increase the weight which then drives down part times as well.

Lastly, materials. Most desktop 3D printers use thermoplastics such as ABS and PLA. These materials are not too expensive, but they take time to heat to the point where they can be used. This takes quite a bit of energy and time to do. This can also lead to clogging of extruders, which would make users dissatisfied with our product. Since our project is dedicated to driving down the cost of a large 3D printer it is imperative that we do not sacrifice quality, and print time in the process if at all possible.



Figure 3: Gigabot 3+ (re3d.org)



Figure 4: 3DP Unlimited large Format Industrial Strength 3D Printer



Figure 5: MakerBot Replicator Z18

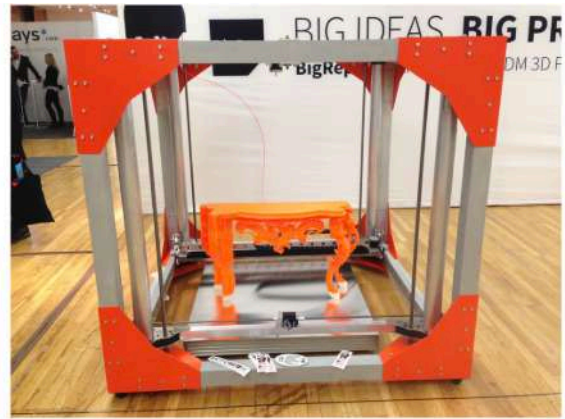


Figure 6: BigRep One (3ders.org)



Figure 7: Large Format 3D Printing Erectorbot



Figure 8: Dimension 1200es

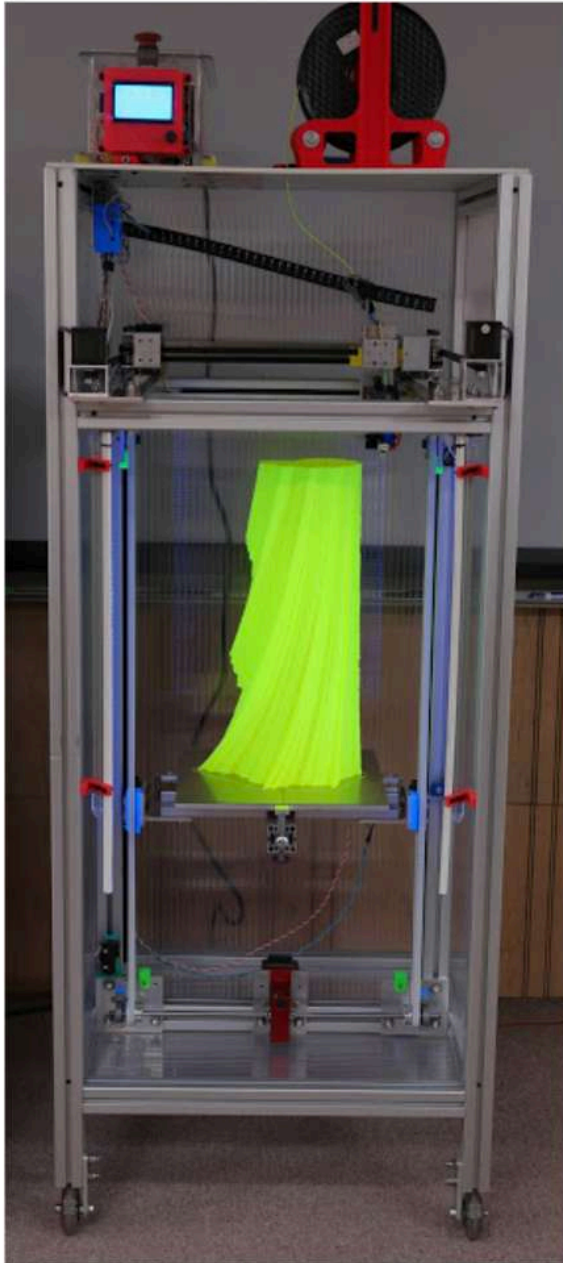


Figure 9: Ultra MegaMax Dominator

(UMMD) 3D Printer

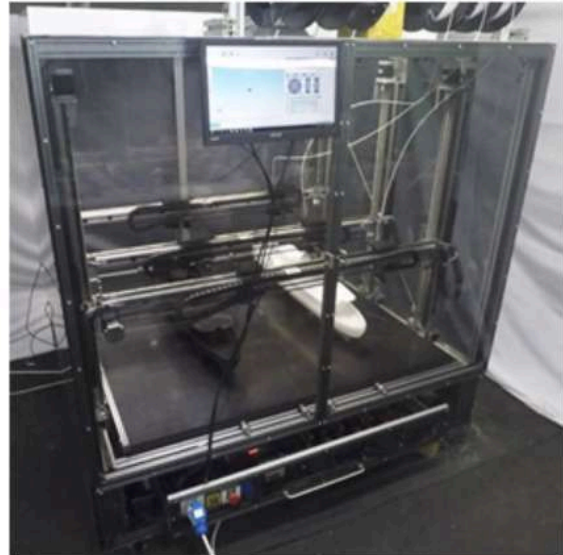


Figure 10: The Dragon large-format 3D printer



Figure 11: MIT robotic arm 3D printer

Table 1: FDM Printer Comparison:

Printer	Type	Volume (mm)	Top Print Speed (mm/s)	Material	Cost (\$)
Gigabot 3+	FDM Cartesian	590 x 600 x 600	100	PLA/ABS/Nylon/B-PET/Taulman/Flex	11,950
3DP Unlimited	FDM Gantry Duel Head	800 x 800 x 780	100	PLA/ABS	14,999
MakerBot Replicator Z18	FDM Cartesian	300 x 305 x 457	150	PLA/ABS	6,499
Big Rep One	FDM Cartesian Duel Head	1005 x 1005 x 1005	140	PLA/Pro HT/Pro HS/PETG approved by BIG REP	39,000
Erectorbot	FDM Gantry	6100 x 2100 x 1860	1000	PLA/ABS	45,000
Dimension 1200es	FDM Cartesian	254 x 254 x 305	NA	ABS	12,900
Ultra MegaMax Dominator	FDM Cartesian	300 x 300 x 690	100	PLA/ABS	1,000
The Dragon	FDM Multi Gantry, 6 Extruders	1200 x 1200 x 800	100	PLA/ABS	TBD (over \$10,000)
MIT robotic arm	FDM Arm	NA	NA	NA	NA (research project)

Additional 3D printers and comparisons can be found at [additive3d.com](http://additive3d.com). Laser sintering, Stereolithography (SLA), metal powder, and other forms of 3d printing have all been eliminated as design routes because of their very large expenses compared to the easily available and low cost FDM alternative. This is why all the 3D printers mentioned in Table 1 are FDM type 3D printers.

### 1.3.2. PATENTS

**Patent number: 8226396** - Automated 3D Build Processes

- o Creator: MakerBot Industries, 7/24/2010
- o Drawbacks: Expensive, Not Open Source
- o Advantage: Produces granulate grains from plastic melt.

**Patent number: 5121329** - Apparatus and Method For Creating 3D Objects

- o Creator: Stratasys, 6/9/92
- o Drawbacks: Basic Model, Bare minimum
- o Advantage: Deposits multiple layers of a material in fluid state

**Patent number: 5939008** - Rapid Prototyping Apparatus

- o Creator: Stratasys, 8/17/99
- o Drawback: Only produces parts in vacuum
- o Advantage: More accuracy

**Patent number: 9688025** - Cleaning object for multi-print-head 3D printing

- o Creator: Stava, 01/08/2014
- o Drawback: Difficult to implement.
- o Advantage: Less maintenance, will help with multi-color printing.

**Patent number: 9688022**- Color or multi-material three-dimensional printing

- o Creator: Chang, 10/28/2016
- o Drawback: Not many people are working with it.
- o Advantage: Multi-color 3D printing





## **2. PROBLEM DEFINITION**



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## **2.1 CUSTOMER REQUIREMENTS**

### **2.1.1 FUNCTIONAL REQUIREMENTS**

#### **For the printer:**

1. Create large scale 3D models
2. Reduce the weight of hot end carriage to allow faster print times and avoid motors from skipping steps.
3. Reliable firmware
4. Multiple heat zones, to save power
5. Independent movement for hot end carriages
6. Heat panels to maintain temperature within print enclosure
7. Print Reliability
8. Low print failure rates
9. Filament holder with humidifier to prevent air moisture from damaging material
10. Auto leveling
11. Dry railing for X and Y motion
12. 14mm threaded rods for z axis motion
13. LCD touch display
14. SD card reader
15. E3D volcano hot end with changeable nozzles
16. Bondtech extruder
17. Minimal Noise Pollution
18. Minimal Exterior Temperature
19. 120V Input Power
20. Used in a well ventilated area

#### **For the printed parts**

1. 200-400 micron resolution
2. No gaps, off centered layers, or impurities in prints
3. Consistent quality throughout multiple parts
4. Sufficient structural integrity

### **2.1.2 PHYSICAL REQUIREMENTS**

1. Print volume 2x2x2 ft
2. Castors attached to base for ease of movement
3. Overall dimensions 2.5x2.5x3 ft
4. Small storage space below for electronics/motors

## 2.2 ASSUMPTIONS

1. The user will have basic knowledge of 3D modeling.
2. We will have a place in the university with enough space to start building the printer.
3. The material of the bed will be strong enough to not bend when holding big 3D pieces.
4. There are low cost softwares available that can control our printer.
5. Changes to the code will be small and relatively simple.
6. Replacement pieces will be available or can be 3D printed.
7. The final product fits through the doors of the building so that we can take it in and out.
8. The printer will work with 120V.
9. Our building space will have available plugs for testing.
10. Each part is readily available online or machinable

## 2.3 CONSTRAINTS

1. Senior design size constraint of 2.5 ft<sup>3</sup>
2. Cost constraint of the dean's funding which is \$1000. Or \$500 per semester
3. Time constraint due to other classes being very demanding
4. Make sure no patents are infringed upon during the design process
5. Needs to run off of 120 V wall outlet
6. Reasonable print time constraint
7. No more than 48 hours left unattended

## 2.4 CUSTOMER REQUIREMENT SQUEMATIC

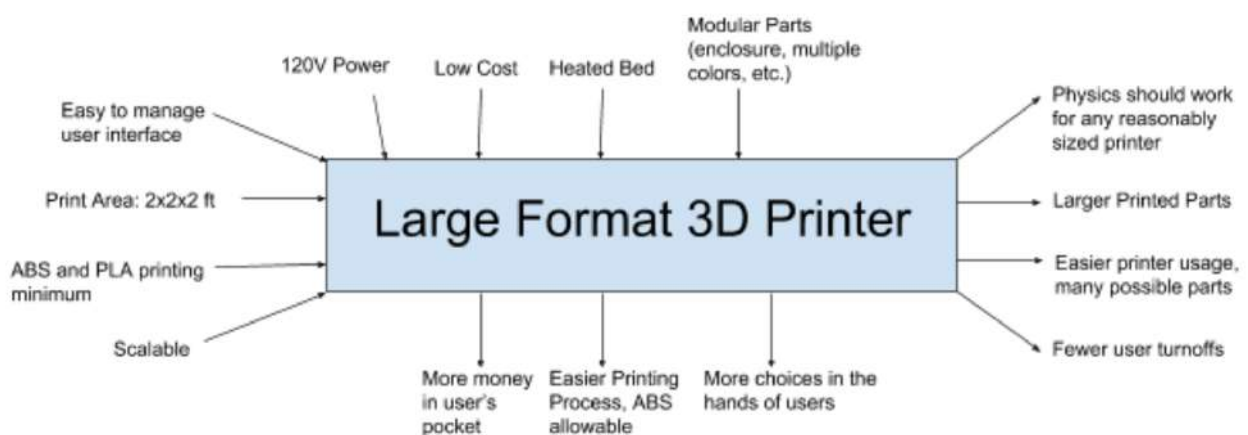


Figure 12: Customer requirement schematic

## **3. DESIGN SPECIFICATIONS**





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## **3.1. DESIGN OVERVIEW**

### **3.1.1. DESCRIPTION**

The overall vision of this project is to innovate the 3D printing community by producing a cheap affordable large-scale 3D printer. Similar size printers on the market today are being sold for more than \$10,000. We are hoping to keep the material costs of the proposed printer under \$1500. Since the project is constrained by the senior design size requirements, it cannot be any larger than a 2.5 ft cube. Even though this is the biggest the printer can be, we hope to learn the skills and principles to scale up our printer to at least double the size. Purchasing 3d prototypes can also be very expensive, especially if they are large. A 2x2x1.5 Ft<sup>3</sup> print can cost up to \$7000. Since the proposed printer will be cheaper than others on the market today, this means prints will be cheaper as well.

Starting from the outside, the printer frame will be made from aluminum extrusions. This design will feature an aluminum bed that will raise in the Z direction. This is advantageous because the goal is to simplify the X and Y axis in hopes of decreasing weight on the carriage which will increase print speed and also reduce the possible vibrations that the X Y Z movement on the extruder could cause. Using the latest technology motors, the goal speed for this printer is 140 mm/s (most printers run at 50-80mm/s). This printer will feature a large volcano heater block that will give the printer a quality of .8mm layer height. Linear dry rails will be a great way to do linear motion for the X and Y axis for this printer. They will provide a very smooth ride for the extruder and can be trusted in long-term use.

Some other features were added to the printer to make it more useful and easy to move, like for example the wheels that help the printer move to different rooms without having to lift all its weight and risk its components after big vibrations. LED lights were also imported to the printer to make the print stand out and be easily seen during night time.

3.1.2. DESIGN SCHEMATICS



Figure 13: Overall design schematic CAD file

After a lot of different options studied for the design, the Figure 13 that is shown in the previous page shows the final design. It represents exactly how the printer was built and is working now, mainly using aluminum extrusions for strength and low cost, and thanks to the accessibility of a small 3D printer in the university, also including a lot of 3D printed pieces that are shown in red color to set aside from the rest. This 3D printed pieces were all designed particularly for their job using Solid Works and are now in perfect conditions and working.

All the different options of the design will be explained further on in this project, and the decision made will be justified with the testing and research that has been done through this year. Every part of the printer went through a decision-making process that chose the actual design instead of many other options that could have worked, but for the use that the printer is built for, the final design has turned out to look like this figure.

The figure is a good description of the basis of the design but the printer built also has many other features that were not planned on the 3D design such as LED lights for a better vision during night time, enclosure, wheels for easy movement or even a live camera that lets you watch how the work is going from home since these prints can take several hours and it is always good to see how the printer is going every once in a while without having to go to where the printer is in person.

### **3.2. FUNCTIONAL SPECIFICATIONS**

- Print Volume: 2x2x2 ft (609.6x609.6x609.6 mm)
- Supported Material: PLA, ABS, Nylon, B-PET, Taulman, Flex (thermoplastic extruding up to 300°C)
- Layer Resolution with a .8 mm nozzle: 200 Microns
- Nema 17 Stepper motor with 200 steps per revolution and a pulley of 12.7mm will result in a resolution of 200 microns
- Printing Technology: Fused Filament Fabrication (FFF)
- Motors: Nema 17 Stepper motor, Step angle of 1.8 degrees, weight of .2 kg, rated voltage of 5v, rated current of .8A, holding torque of 26 N-cm
- Extruder/Heater block: E3D Titan Aero, available in 1.75 and 3mm, 12v and 24v as well as standard and mirrored varieties. Comes with V6 0.4mm Nozzle
- Power Supply: Eagwell, 24 V, 15 Amps, 360 W, DC Universal using 120V input
- Frame: Aluminum extrusions, 40mmx40mm, 6105-T5 aluminum

### **3.3. PHYSICAL SPECIFICATIONS**

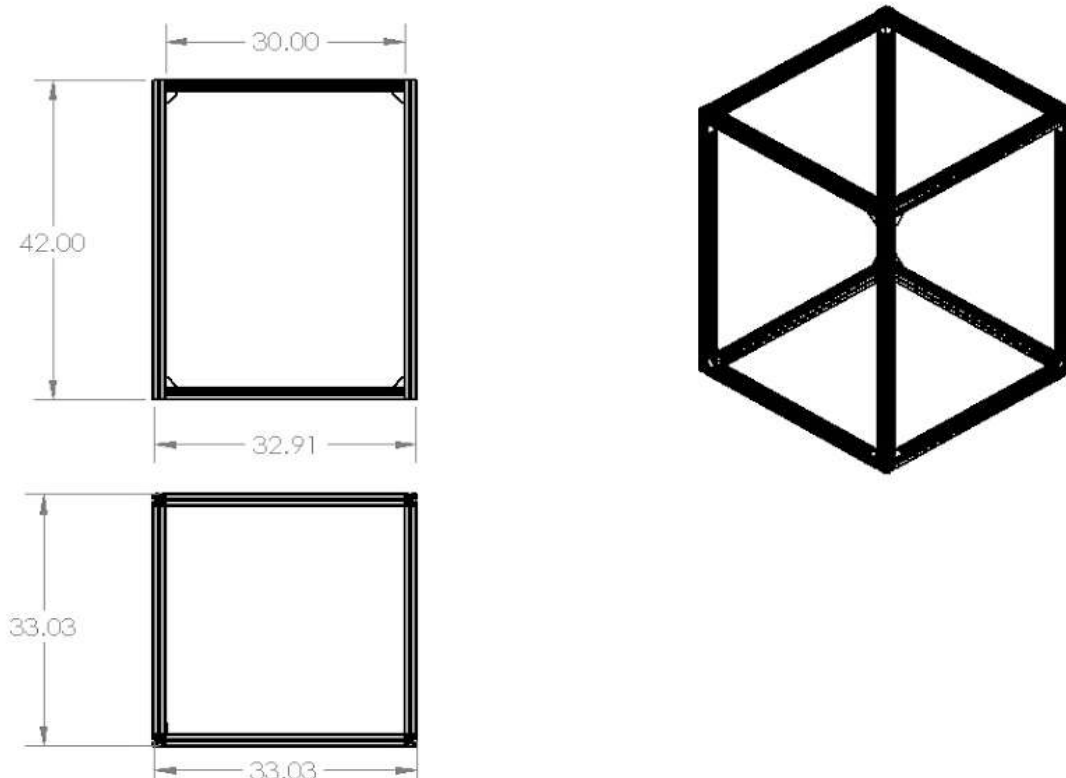


Figure 14: Side and Top View of Frame with Dimensions



Figure 15: First design CAD File Frame with gantry, bed, and enclosure

**DIMENSIONS:**

Outside volume: 22.9 ft<sup>3</sup>

Inside volume: 17.1 ft<sup>3</sup>

Frame's total weight: 21 pounds = 9.5 kg

When the enclosure is closed and locked, it will provide rigidity and shear support to the printer which will help from wobbles and decrease printing errors. The enclosure will also help to keep the temperature as stable as possible, since the 3D printing process is very sensitive to temperature.





## **4. DESIGN ANALYSIS AND RESULTS**



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## **4.1. SYSTEM ANALYSIS AND DESIGN**

### **4.1.1. DESCRIPTION**

This project was developed to innovate the 3D printing community by producing a low cost large scale 3D printer. Similar size printers on the market today are being sold for more than \$10,000. Due to part selection the bill of materials should be as low \$2000, if not lower. One constraint on the system through the senior design course is the size. The senior design course allows for up to 2.5 ft in each dimension, but this the final design exceeds this limit. The final dimensions of the printer will be 2.75x2.75x3 ft, which is not too much larger than the original constraints. This has been deemed acceptable based on the objective of the project. Purchasing 3D prototypes can be very expensive, especially if they are large. A 2x2x1.5 Ft<sup>3</sup> print can cost up to \$7000. Though cost of material will not decrease because print material is outside the specifications of the design objective, the overall cost of the printer will be decreased which can in turn reduce the cost of each print.

Starting from the outside, the printer frame will be made from aluminum extrusions. The design will feature an aluminum bed that will raise in the Z direction using lead screws and guide rails for stability. This is done to simplify the X and Y axis in hopes of decreasing weight on the carriage which will increase print speed and also reduce the possible vibrations that the X Y Z movement on the extruder could cause. Using the latest technology motors, it will have the printer run at a speed of 140 mm/s (most printers run at 50-80mm/s) so that the big prints can go as fast as possible without losing too much quality on the final piece. It will use a large volcano heater block that will give it a quality of .8mm layer height. A carriage that attaches the frame will be the best bet for linear motion because it is cheap and effective opposed to other options.

In terms of electronics, since the printer's design has space for storage on the bottom of the bed, it will use a LCD screen connected to a Rambo board that will make it easy to use by people that are not experts in the field. Comparing to a printer that you have to keep connected to your computer in order to use it, our LCD screen will allow it to work by simply connecting an SD card with the respective STL file you want to print.

### 4.1.2. DESIGN SCHEMATICS

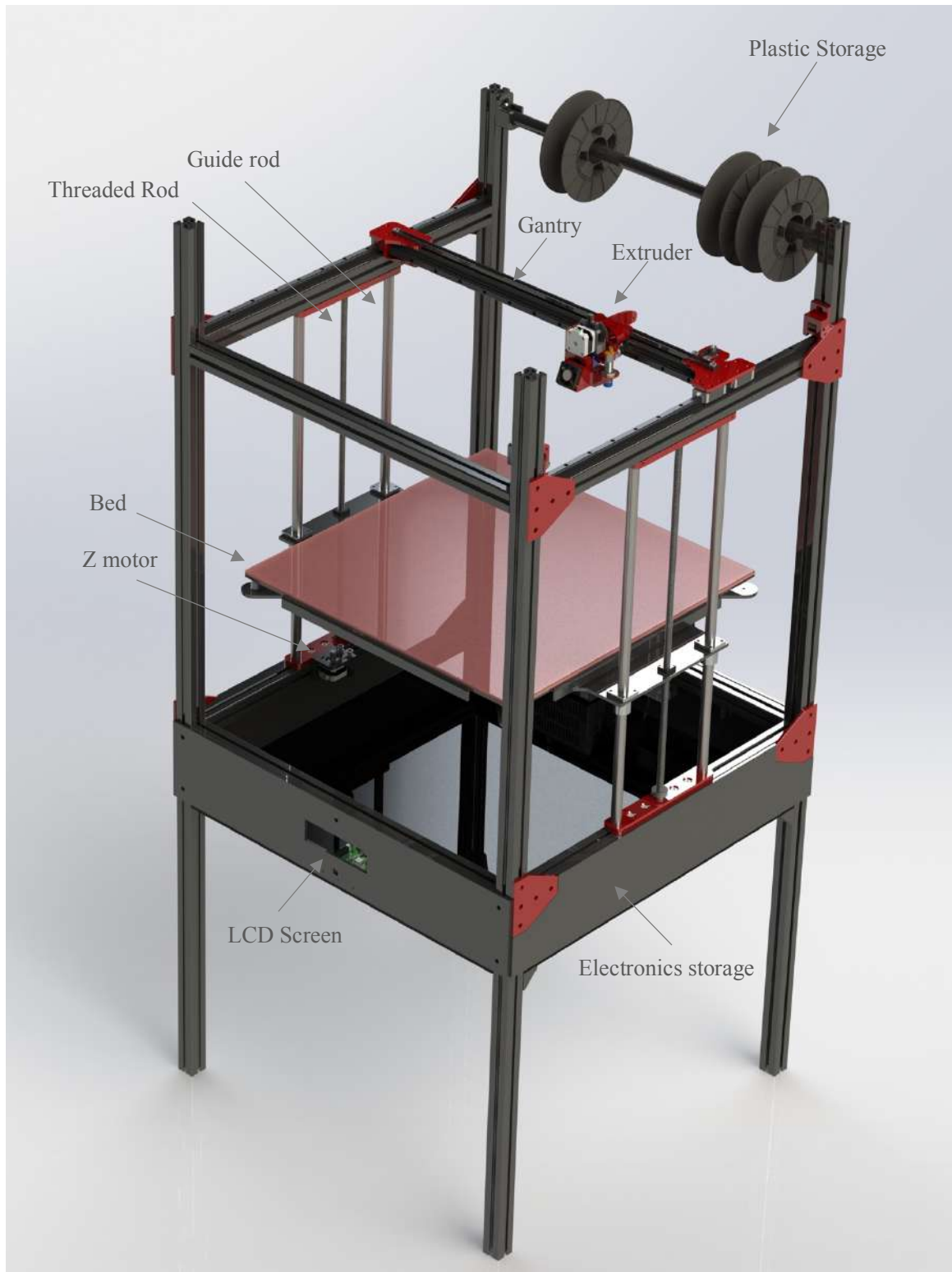


Figure 16: Part schematic

## **4.2. SUBSYSTEM ANALYSIS AND DESIGN**

### **4.2.1 EXTRUDER**

For the extruder, the E3D Volcano will be used for the proposed design. This extruder was designed around the Nema 17 stepper motor to save space and maximize efficiency. The heat sink is integrated with the extruder saving 2 inches in print height. The 3D printed gears allow for maximum torque, minimizing the possibility of the stepper motor skipping steps.

This extruder was chosen because of its big plastic flow rate that could accelerate the prints a lot, and its proven long-term durability that has been found through the research. Many well recognized 3D printers use this extruder, and although the printer is designed to reduce the cost, this piece is a key factor to the quality of the prints and it is one of the subsystems in which the budget has to be spent on, and even being a high-quality extruder that comes with its fan and heated block, it only costed \$115.



Figure 17: E3D Volcano Extruder

Before buying our power source and our extruder, some calculations had to be done to make sure that every piece imported could work with our design. Below are the calculations for flow rate as well as power required.

$$Q'=m'C_p(T_o-T_i)$$

$$V_i \cdot D_i = V_o \cdot D_o$$

$$m' = \rho \cdot \text{Volumetric build rate} = \rho \cdot A \cdot V_o$$

Desired Output Velocity: 120 mm/s

Table 2: Extruder power calculations

Nozzle Diam (mm)	0.4	0.8	1.2
Area (mm <sup>2</sup> )	0.1256637061	0.5026548246	1.130973355
Volumetric Build Rate ((mm <sup>3</sup> )/s)	25.13274123	100.5309649	226.1946711
Velocity In			
Filament Diameter (mm)			
1.75	45.71428571	91.42857143	137.1428571
2.85	28.07017544	56.14035088	84.21052632
Q' (ABS) (W)	8.6	34.4	77.32804122
Q' (PLA) (W)	10.5	41.8	94.15353183

This table shows that even at the maximum case scenario, the printer will only need to provide 41.8 W of power when using a 0.8 mm nozzle diameter. It is important to note that a normal printer uses a nozzle diameter of 0.3 or 0.4mm, and that a 0.8mm nozzle is a big gain of speed in terms of print times.



After choosing the extruder, one of the biggest issues is to design an attachment that can hold it still while moving rapidly on the X and Y axis. This is why it was chosen to have a 3D printed piece that could attach all its pieces together and bring stability to the prints. For this, the printer could use a design of attachment that can be changed and tested along its use.



Figure 18: E3D Volcano extruder

This figure shows the final design of the extruder and its attachment to the gantry. The red colored part is a 3D printed piece that was designed in order to be able to attach the extruder to its two fans, its motor and the gantry. It also includes two holes that allow it to grab the belts and move on the X direction.

This carriage went through a lot of different designs because of its huge weight support and the fact that the print is very sensitive to vibrations on the extruder. For that the design grabs onto the dry rail and the gantry using four screws that go all the way through the printed piece and through the fans as well. This helped to keep it as steady as possible and after testing it with high speeds and weights, it proved to be the best design and won its place on the printer.

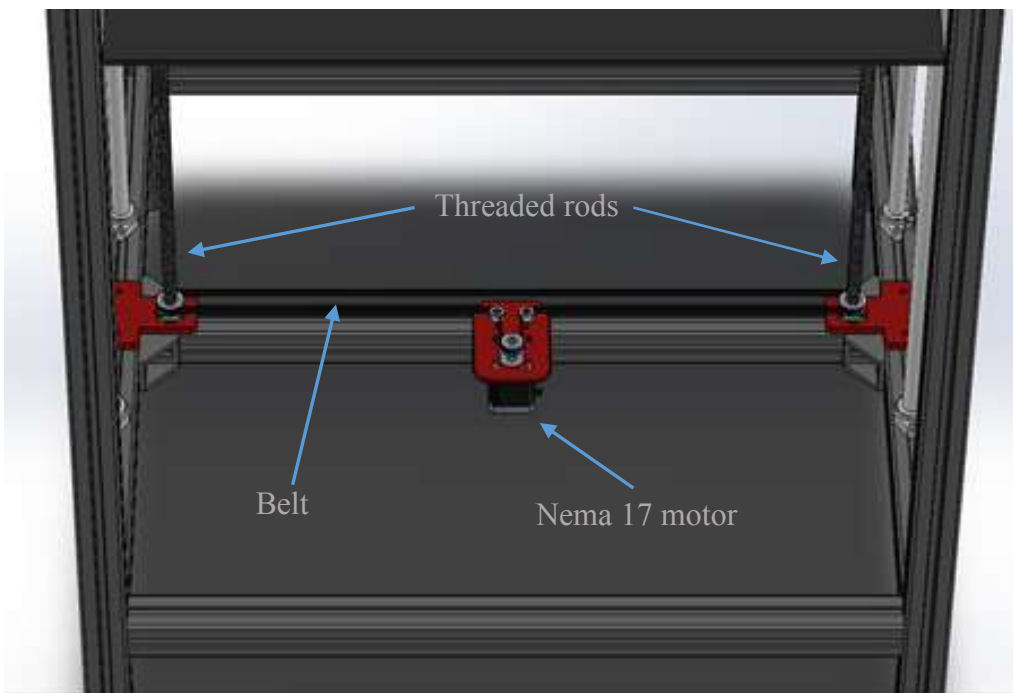
#### 4.2.2 BED (Z AXIS)

For the design of the Z axis, it will move independently from the extruder to avoid even more vibrations on the print. This is why it was designed to move up and down using threaded rods for movement and guide rails for stability and parallelism. Note that if the bed skips 0.5mm, the print would automatically stop working since the extruder would be printing on the air. This is how important this subsystem is on this whole project.

The Z axis includes two 8 mm ACME threads that will easily hold the weight of a large print and move the bed at reasonable speeds. Using 4 rods the stability of the heated print bed is increased for maximum accuracy and reduces moments on the supports. Many 3D printers, like the Ultimaker 2+, only have one lead screw, though this may not be an issue on a 1x1 bed, the moments in this 3D printer bed would be too much for the guide rods and screw to handle.

The fact that the bed will have 2 threaded rods and 4 guide rods makes it very hard to build. Alignment between two large rods is very hard to accomplish because a small difference of angles can cause a difference of centimeters from top to bottom. That is why making 6 bars parallel is a very hard task. For that, a new 3D printed piece was designed that could give a freedom degree to these bars so that they could move a small distance on their base and avoid possible misalignments on our system.

As shown below in figure (19), the printer has both threaded rods driven by the same motor using a design that will make sure both rods rotate the exact same to avoid one rod being off from the other and making the bed tilt. For that we have a belt that goes through the whole section underneath the bed and wraps around both lead screws and the motor. This design was chosen because it is known that the motors can sometime skip steps if the tension is not the best for its teeth or if the motor is not strong enough.



Figures 19: Z axis movement

A silicone heating pad adhered onto a steel sheet was utilized to make sure the prints do not lift up while printing. By heating the steel sheet and allowing for the heat to transfer through a 6 mm glass plate, parts adhere better to the bed during printing, which is crucial for any successful print. This is because if the base of the print is cold, the material could solidify completely and then come off the bed, ruining the whole print.



Figure 20: Heated Bed

The sheet metal plate has bed clips to make sure the glass above stays in the appropriate position and ensures that the two components are sandwiched together. If the steel sheet and glass are not uniformly connected to one another then the proximity sensor will detect false readings given by the steel sheet not knowing the glass is higher in some positions, this commonly leads to the nozzle crashing into the bed and can damage the glass, the part that is being printed or even the extruder's nozzle. Under the steel sheet and heated silicone pad, there is an aluminum "spider" bed used for overall subsystem stability. This "spider" bed bridges the connection between the linear guide rods, ACME lead screws, and the moving Z axis bed. The aluminum spider bed was particularly designed and laser cut for this job and is attached to the ACME lead screws via lead nuts.

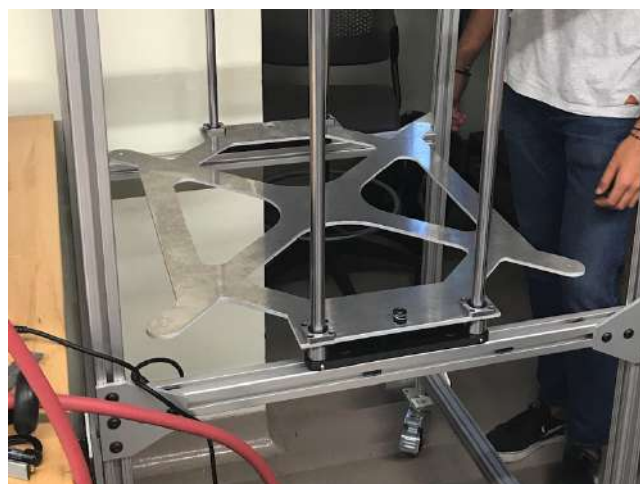


Figure 21: Spider bed

### 4.2.3 XY LINEAR MOTION

One of the largest and most complex subsystems for 3D printers is linear motion. Linear motion is a complex topic with many design and manufacturing considerations. This printer will work with a moving extruder attached to an aluminum extrusion (X axis) that will be the gantry for this design, and at the same time this gantry will be attached on both sides to its linear motion system being the Y direction. The gantry will only be motorized from one side, leaving a slave side on the opposite side of the printer. This is to avoid the structure to collapse in case of a skipping motor on one side that would be pushing the gantry forward from one side and still from the other. This could also harm the dry rails if the motors are powerful enough to damage them.

The gantry is a 30x30 aluminum extrusion that can hold a lot of vertical force without deflecting too much as shown in the Figure 22. It was also chosen to be aluminum because the gantry and all its weight due to the extruder and the motors will have to be carried and pushed only from one side with a NEMA 17 motor, and for that it was to be as light as possible in order to avoid possible motor skipping and to reduce the torque needed to apply to move it at a certain speed.

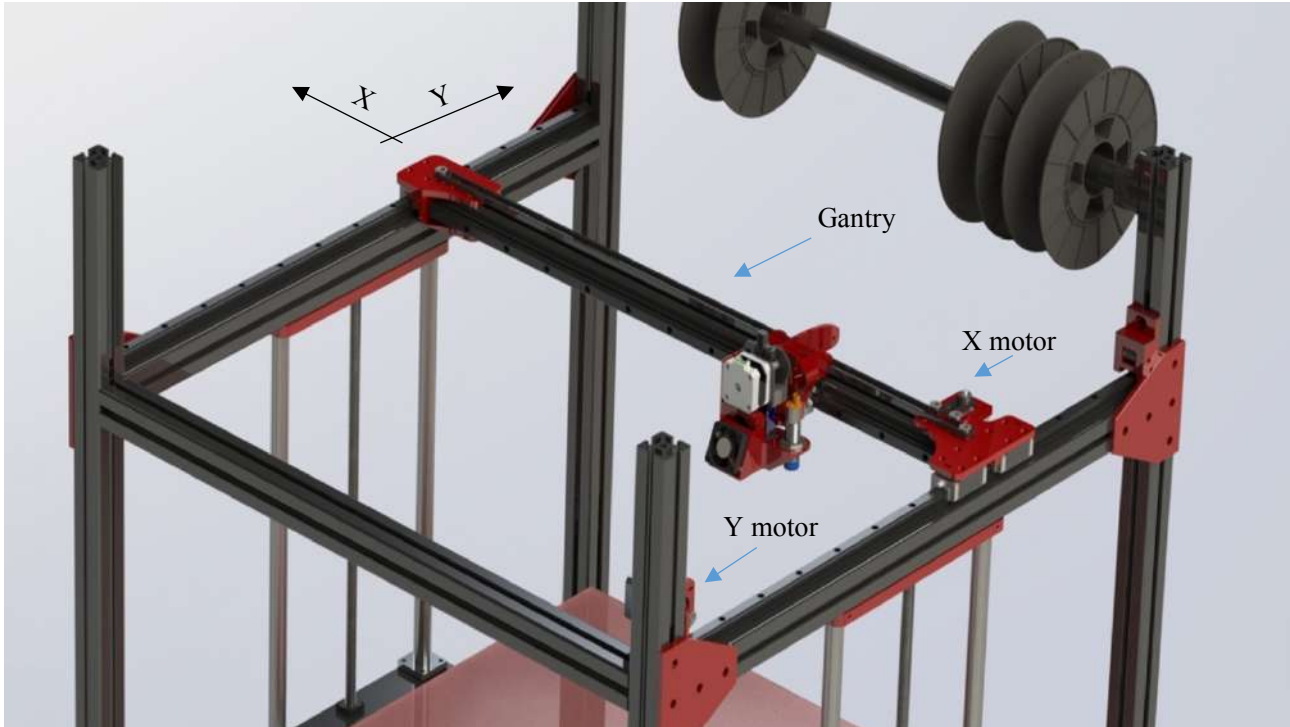


Figure 22: X and Y linear motion

The linear motion system must be light weight not only for speed purposes, but also for layer height considerations. Knowing that for a proper print, the layer height is typically set to be at a maximum of  $\frac{1}{2}$  the nozzle diameter and at a minimum of  $\frac{1}{4}$  the nozzle diameter, and using a 0.8mm nozzle for the prints, deflection must be lower than 0.2 mm (200 microns) if you want it to be precise and with high quality.

Below is a sample of the Finite Element Analyses performed using Solid Works for the aluminum extrusions under a fixed end position. From this the total deflection of two members was determined with the loading of the extruder, hot end, motor, and more (using a worst case scenario of placing the loads in the center of beams). The maximum deflection was found to be under 50 microns thanks to the high strength of the aluminum profile chosen.

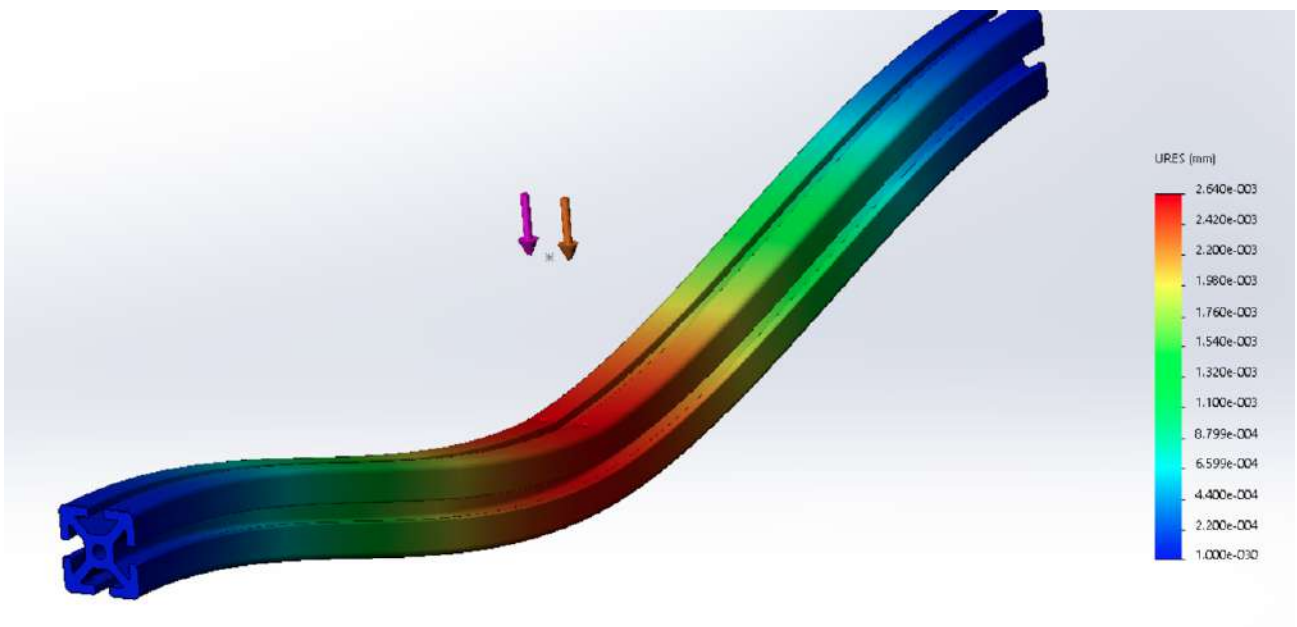


Figure 23: FEA of 3030 Aluminum Extrusion

This is under an ideal scenario and a simulation where the beams are constructed perfectly and assembled firmly on both sides. During the construction process the beams must be assembled carefully to ensure the deflection is minimal and then be able to say that the simulation is very close to its real construction. Many linear motion systems fail due to construction imperfections or bad assemblies, so it is crucial to make sure that every component is well assembled.



At first, the design was meant to use a 3D printed piece that would attach the gantry to the dry rails on both sides, but after trying some plastic designs, they all ended up crashing the gantry, breaking or deflecting too much. This is why, for the gantry, it was chosen to build a specific aluminum design that can attach the aluminum extrusion to the dry rails strongly and not with a 3D printed piece for this specific part of the printer, as the next figure shows.

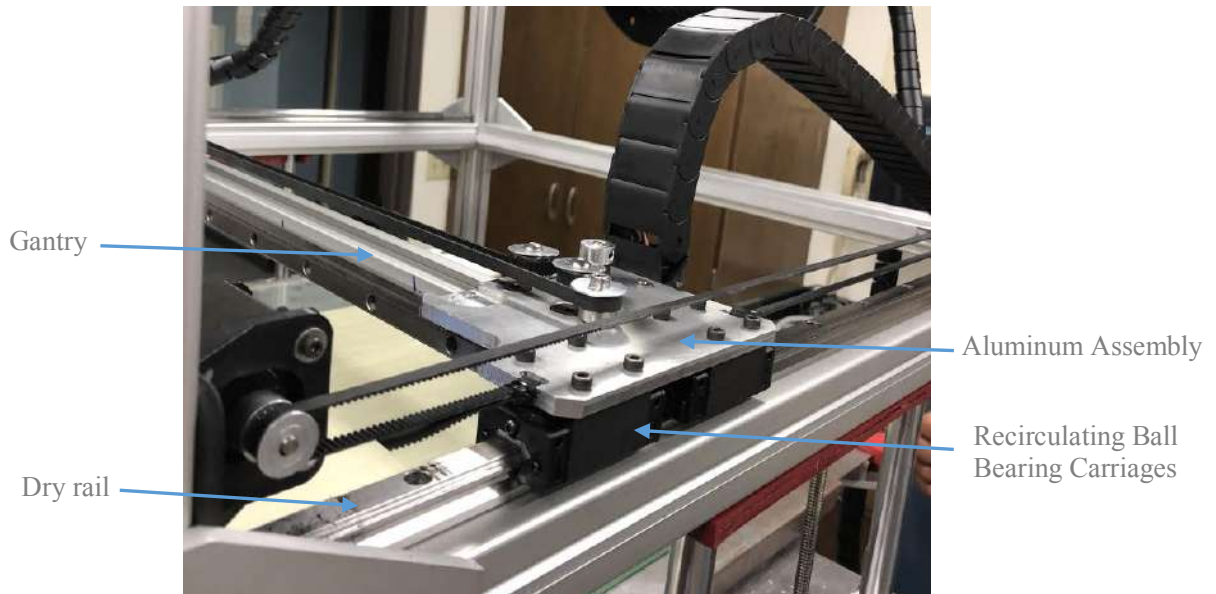


Figure 24: Aluminum assembly for the gantry

There are also many different options of movement like linear rods, carriages and a lot of other options that use wheels or low friction sliders, but for this printer the XY linear motion system will make the use of dry rails with recirculating ball bearing carriages for increased accuracy as shown in Figures 21 and 22. These dry rail and recirculating ball bearing carriages require little to no lubrication that makes them the best choice for long-term usage, while having incredible accuracy necessary in linear motion systems. They also have the ability to connect directly to the frame aluminum extrusions via t-slots in the aluminum extrusions. By directly attaching the linear motion system to the frame the print volume will be maximized without having to deal with further options of attachments. The disadvantage of the system is the price because these rails can cost well over \$150 for a 100 mm rail length. However, only the XY linear motion system will only use one dry rail for the X movement and two for moving the gantry (Y movement).



Figure 25: Dry rail system

Compliance is another consideration necessary in linear motion design. Manufacturing is always necessary in any design process. CAD is always assembled perfectly when in reality parts can be machined incorrectly or with too high a tolerance. Linear motion systems need to be assembled in perfect alignment, which is impossible to accomplish. Therefore compliance needs to be addressed in this subsystem.

Because our printer is a big volume and all held by 3D printed parts that have a small flexibility if the force is strong enough, the issue of compliance is solved by attaching aluminum pieces with plastic parts and if it is not enough, like on the Z axis, mounts that leave a degree of freedom for movement when the system has too many constraints can be designed.

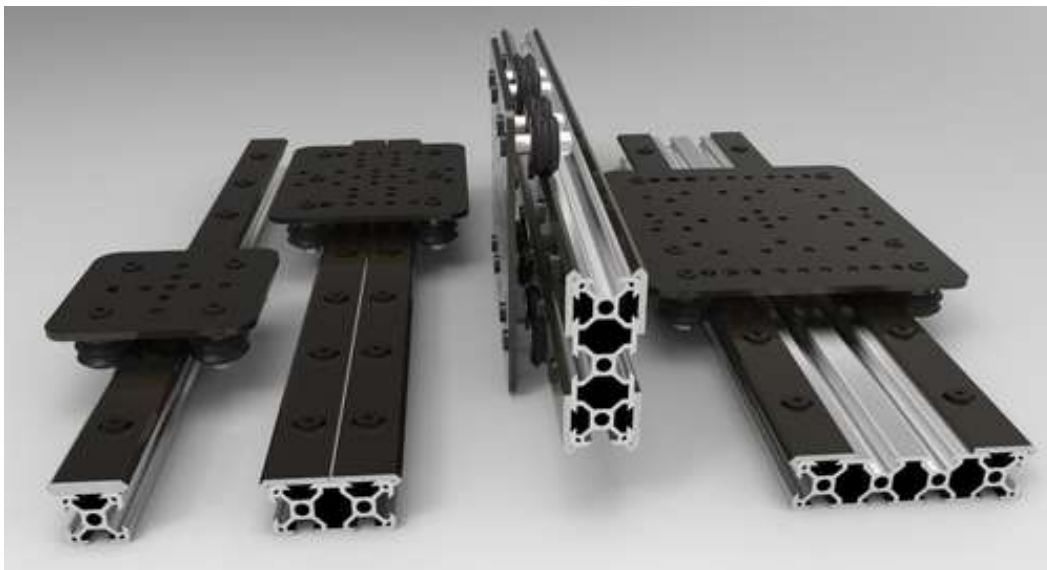


Figure 26: Design options for aluminum extrusion attachments for compliance

The XY linear motion system will be belt driven. The belts will consist of normal 6mm width, 2 mm pitch, gt2 timing belts shown in Figure 23. Since the motors are standard Nema 17, the bore of each timing pulley will be 5 mm. With this information and the fact that each has 20 teeth, the pitch diameter is 12.7 mm. The hope is to have linear motion up to 120 mm/s. Though this is dependent on drivers it is also dependent on loading and motor selection.

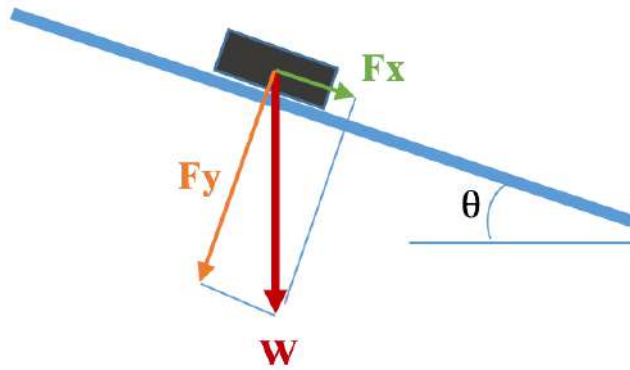
$$\text{Velocity} = \text{angular velocity} * \text{Radius}$$

$$\text{Angular velocity} = 120 / (12.7 / 2) = 18.9 \text{ rad/s}$$

Knowing this, and with a pitch diameter of 12.7mm, the printer will need a motor that can run at angular speeds of at least 3 revolutions per second. The Nema 17 motor can work with speeds that are much higher than this, so it will work for the project.



The coefficient of friction was calculated testing the dry rail by leaning the rail until the carriage started moving. The carriage weight was measured to be 0.318 kg.



In the moment just before the carriage starts sliding:

$$F_x = F_{roz} = W \cdot \cos(\theta) = F_y \cdot \mu$$

Angle of movement	4.1	3.8	6.5	3.9	3.6	6.7	4.2	6.6	3.5	5.7	5.3	3.9
Angle of movement (radians)	0.0715584993	0.066322	0.113446	0.068067	0.062831	0.116937	0.073303	0.115191	0.061086	0.099483	0.092502	0.068067
Weight (kg)	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318
g (m/s^2)	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Fw	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164	3.1164
Fr	0.2228146355	0.206535	0.352786	0.211962	0.195680	0.363592	0.228239	0.358190	0.190251	0.309520	0.287863	0.211962
Fn	3.108424456	3.109548	3.096367	3.109183	3.110250	3.095117	3.108030	3.095746	3.110587	3.100991	3.103076	3.109183
Coefficient of friction	0.0716808912	0.066419	0.113935	0.068173	0.062914	0.117473	0.073435	0.115703	0.061162	0.099813	0.092767	0.068173
Average	0.0843044048											

Table 3: Test for coefficient of friction

As the table shows, the coefficient of friction is very low with a value of 0.084. This makes the linear motion very efficient and will allow the printer to use smaller motors and less energy.

Many Nema 17 motors have holding torques of 26 N-cm or more. With these Nema 17 motors, the Rambo Board (discussed in Section 4.2.4), and the dry rails, the printer has been able to print at speeds up to 110 mm/s. Though speeds above this are possible, at these speeds a mechanical problem did arise recently and that is skipping in the Y axis due to low belt tension at sudden direction changes. This arose because the belt is so long, approximately 60 inches, because it has to go the full internal length of the printer and back. The solution has yet to be fully implemented, but it consists of a 40 teeth timing pulley being supported by the aluminum extrusion closer to the Y axis drive motor. This will allow the belt to be tensioned at two places and will hopefully solve the problem.

Belt tensioning is one of the biggest issues that the project encountered at the end, and for that a new motor mount was designed that had the ability to put the belt in place and give it some extra tension that helped a lot through the print. This design was made with a small 3D printer and is on the actual product, on both X Y and Z axis.

There is another way to maximize the tension that was used throughout this project and it is very common among 3D printers. It consists of a metal clip that makes the belt more tense by forcing it to curve on a straight line and then applying pressure on it. It is very easy to put and also very cheap but it is not very good looking and is not going to be there on the final design. The following picture shows one of these belt tensioners and how they can be applied.

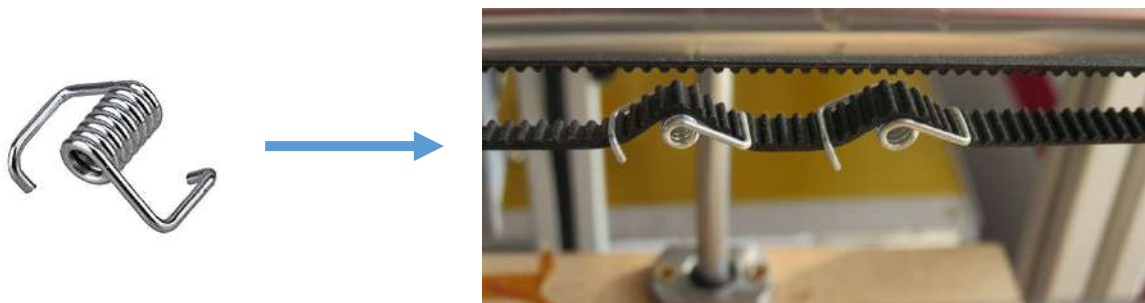
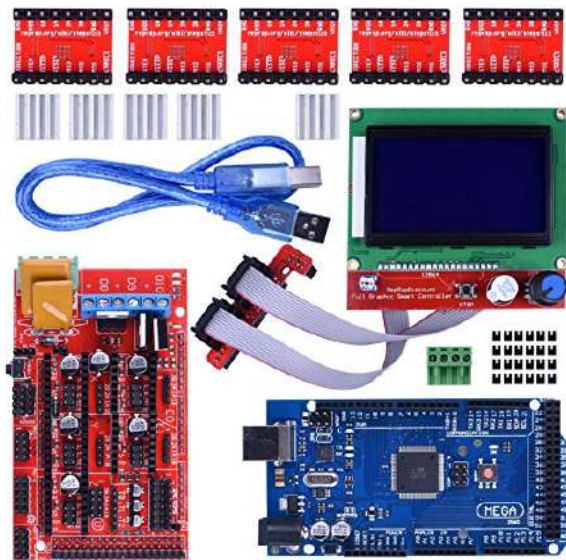


Figure 27: Timing Belt and Belt Tensioners

These belts are very strong and can work with really high tensions for long period of times, but due to these belt tensioners, the belt can sometimes be damaged and lose part of its teeth, causing it to skip. This is why the final design will not have these tensioners, but for now and for testing, they can be very useful while trying to find the best tension for the printer. Once the optimal tension is found and selected, it will be achieved without them.

## 4.2.4 ELECTRONICS/SOFTWARE

The final subsystem to the design is the electronics / software. The electronics are run off a monolithic board called a Rambo Board. The Bambo Board is an Arduino variant designed specifically for 3D printers. It is used in many commercial 3D printers and is considered one of the best boards available for 3D printer electronic applications. This is because it has built in safety mechanisms like fuses and is very easy to work with. The code consists of free open source software to use for the motion control of the printer called Marlin. Marlin is used by many 3D printers for commercial use, including the famous Original Prusa i3 printers. The slicing program used to convert solid models into g-code for the Rambo board to understand and execute is called Simplify3D. Simplify3D is a well known and popular slicing program because it has many features not available in free slicing program. Luckily a team member already purchased Simplify3D for personal use and the team was able to use it to print parts and assess the printer once it was complete.



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Figure 28: Electronics package

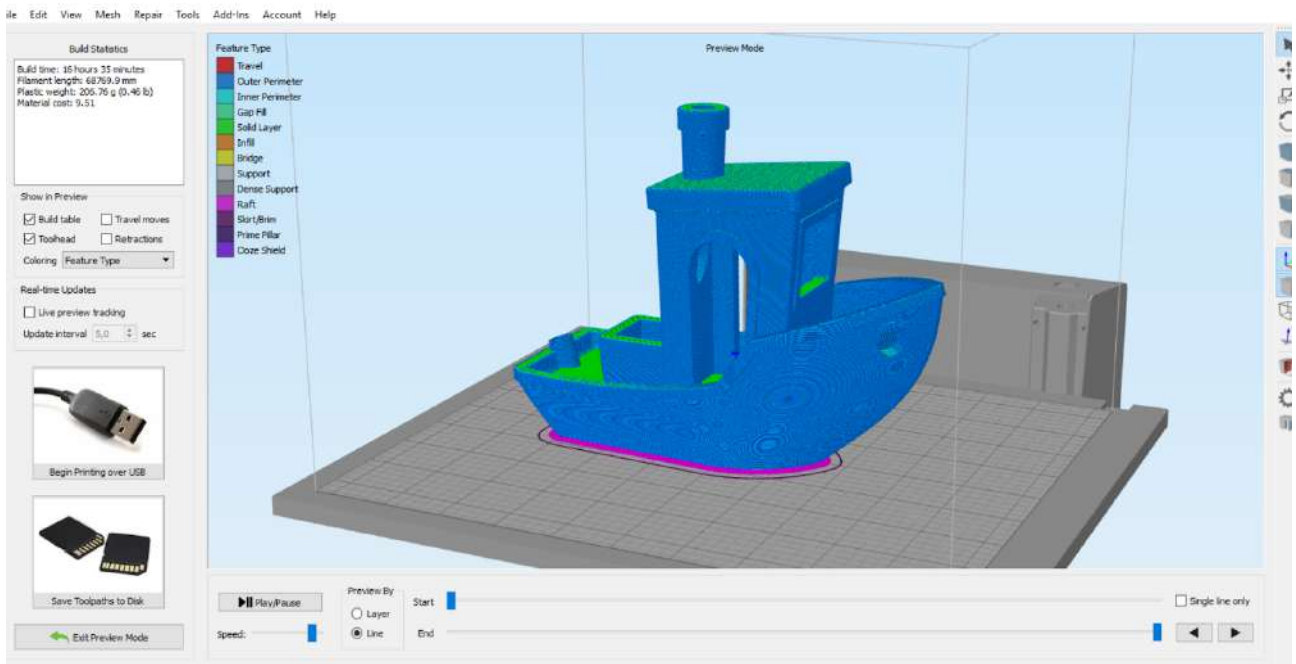


Figure 29: Simplify3D Software



Figure 30: Nema 17 micro stepper motors

The electronics fit into the built-in space below the printer for easy and clean storage. For the motors, using the least amount of motors possible will make the build more simple and therefore increasing repeatability. Using the same micro stepper motors (Nema 17, 24 V) throughout the printer will simplify the buying process. These motors are the best in business and can produce speeds up to 120 mm/s with ease.

An LCD screen was added so that the printer could print on its own via an SD card that plugs straight into the LCD, without needing a computer nearby. This was successfully attained, but most of the test prints that were conducted were done via a laptop. This is because it is easier to troubleshoot potential problems during a print if necessary, and it is common on the first tests that the printer will need a few adjustments while it prints.

#### **4.2.5 FINAL IMPLEMENTATIONS**

Besides the electronics used for the printing process a couple of features were added for user friendliness and energy efficiency. The heated bed is connected to a Solid State Relay that connects straight to the incoming 120 V wall outlet supply. This allows the heated bed to get up to temperature within a few minutes (about 3 minutes to get up to 65 degrees Celsius). This cuts down time and energy in losses while the bed is heating up. A regular wall outlet was also connected to the 3D printer that gets its source of energy from the incoming 120 V wall outlet as well. This gives the user the ability to plug in any 120 V electronic into the printer and use. Some applications used by the printer have included plugs for charging the laptop that was running the slicer programs, and a strip of LEDs so that the printer can be plugged into a wall outlet and have its own source of light at any time. This is important for long time printed parts where a user might want to turn off other lights but still have the ability to see their part being printed.

Most of these new implementations were added because during the last semester, the project was going very well and the University of San Diego decided to give another \$1000 of budget to the project. When the budget was received, the project itself was almost done and built, so this new money was spent on new gadgets and functions that were not necessary for the printer to work but did help make it a bit better looking and easier to use. For example, a live camera was bought and put on top of the printer so that anyone that leaves the printer working for a long time can check the state of the print by simply opening an app on your smartphone and seeing that everything is ok, without having to physically go check on the printer every once in a while. It was crucial for the camera to have those LED lights that could light up the printer during night time.





Figure 31 :Castors for easy movement



Figure 32: LCD Display



Figure 33: Extra strength corners

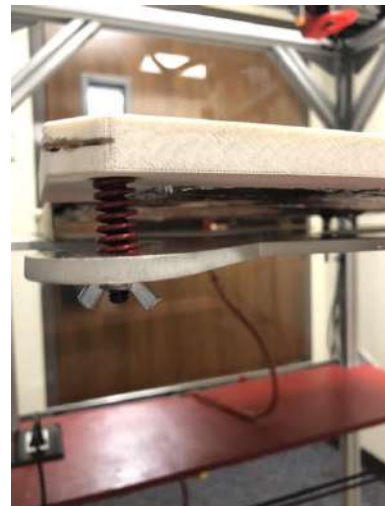


Figure 34: Bed levelers

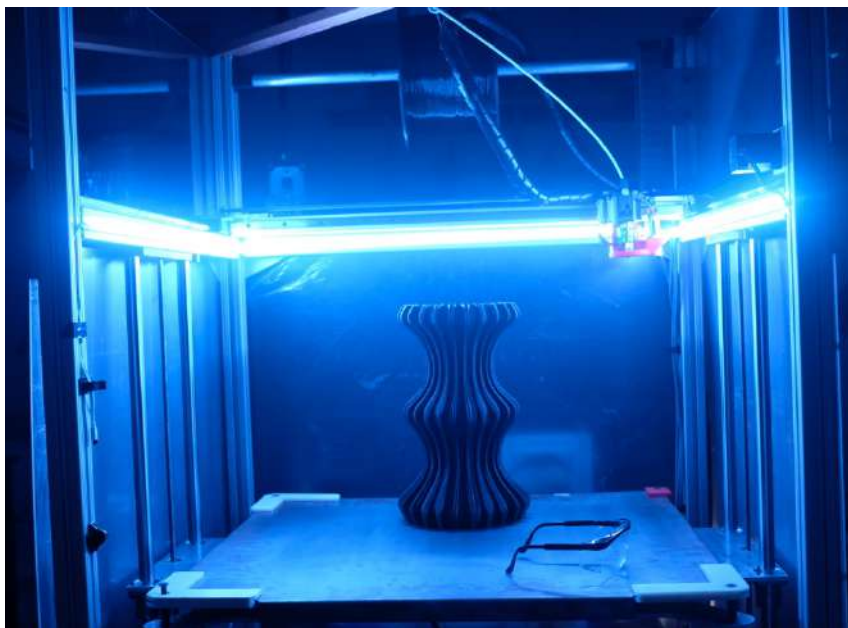


Figure 35: LED Lights

## **4.3. RESULTS**

### **4.2.5 FINAL PRODUCT**

The final product is very similar to what the first design looks like including the final implementations that were explained on point 4.2.5. and it is how the printer looks at the moment.



Figure 36: Final product





Figure 37: Final Product

## 4.2.5 TESTING

After finishing the project there was time for testing and printing some parts that are typically printed for the first tests. For those tests some different speeds were tried, variations on the acceleration and temperature were made so that the print could look as good as possible.

A typical issue that printers face is the fact that this method is based on printing layer over layer, and when an overhanging piece has to be made, plastic could fall down and not print at all. The following figure shows how when a printer encounters an overhanging part it cannot print well since there is no plastic underneath the extruder where the melt plastic can be deposited.

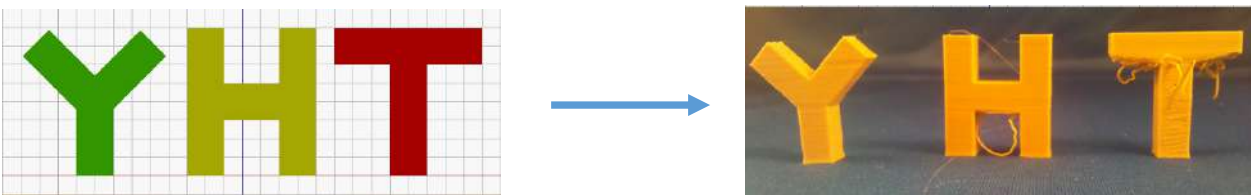


Figure 38: Overhanging issues

For testing this common issue, it was decided to print a small boat that is known because of the multiple overhanging sections on the front and the doors that it has and also because of how hard it is to achieve a well printed prototype of this shape. The following figure shows how the project's printer overcame this issue and was able to print the boat with no problem at all. It is important to note that this was the first ever print the project had done.

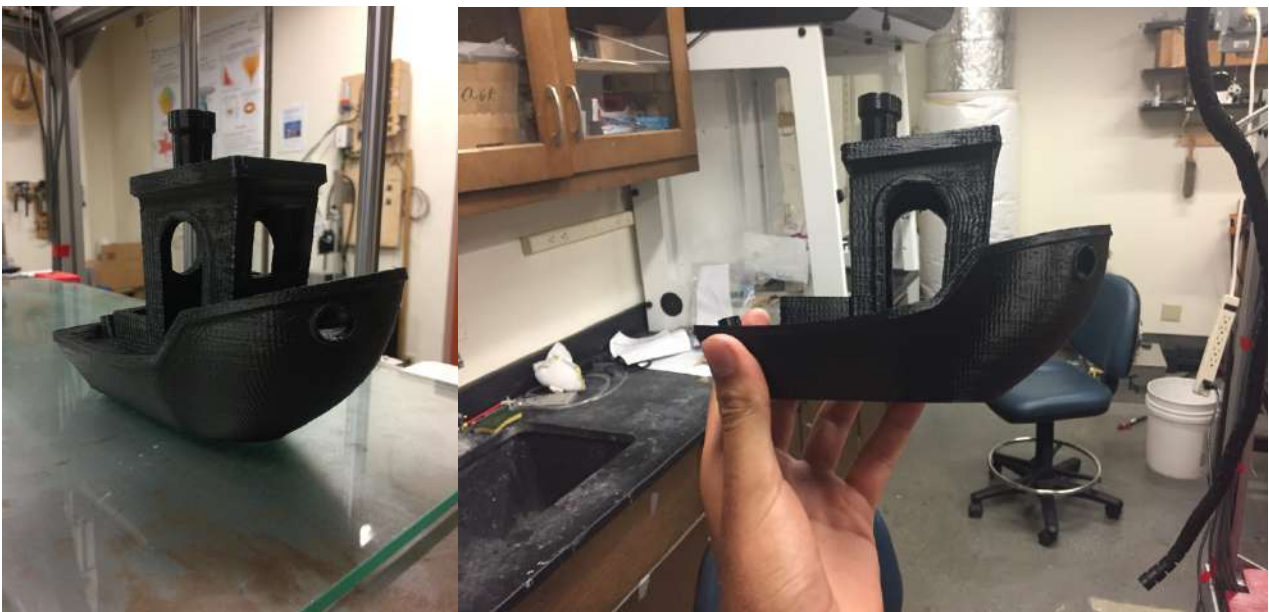


Figure 39: Overhanging Test

Another issue that printers have to face, specially large format printers, is printing times. To print a big piece can take more than a full day and this means that the machine cannot skip steps or wobble during a lot of hours. The project was tested on its durability printing a large piece called base that took over 12 hours. With this piece the Z axis was also tested due to the height of the base.



Figure 40: Speed test

Finally, since the printer had passed all the tests that were considered important, the next print was a functional wrench to show what a printer can do. In normal manufacturing you would have to create the wrench and the screw separately and then join them together, but for a 3D printer it is an easy job and a 1 print piece.



Figure 41: Functional test



## **5. PROJECT PLAN**



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## **5.1. CONSTRUCTION**

Many components of the 3D printer will be purchased through online retailers and manufacturers. Other components will be machined in the Machine Shop or 3D printed in Donald's Garage. Construction of the printer will start from the outside and go in. To construct the printer, many of the shops in Loma such as the machine shop and 3D printers in Donald's Garage will be used. The frame can be held together with a variety of materials such as machined metal or 3D printed components that are already available on Thingiverse or designed by the team on Solidworks. Each subsystem will be built individually before installing each component to the 3D printer. Constructing each subsystem outside of the frame will give the team more space to work on intricate details if necessary. Assembly of the printer will take place in the machine shop or Donalds Garage. The team will be using machining processes such as milling, turning, sheet fabrication, and 3d printing to construct any components more specific to our design. For example, many bed components will be 3D printed because of their intricate and specific designs.

## **5.2. SAFETY ASSESSMENT**

3D printers are relatively safe machines to use, but there are some areas of concern for any users. One area of concern is the burning of plastics in a confined space. 3D printers are meant to be used in well ventilated areas. This 3D printer will mostly use PLA and ABS plastics, which can be toxic if a user is exposed to nanoparticles in the air. Placing the 3D printer in a well ventilated area will solve this problem. Also, 3D printers use hot ends and heated beds that can reach very high temperatures. If a user touches these while in use then they can be burned, this is more likely to occur with the hot end reaching temperatures as high as 250 °C. Users should make sure they do not touch these components while they are in use. Lastly. There are linear motion components. Some components move at medium velocities that can injure a user if they place any body member in the machine while in use. This can also be solved by ensuring users do not place body parts in the 3D printer during use.

The team will have to be very careful with electrical current to make sure no shocking hazards are created during the wiring process. Safety measures will be taken to ensure user safety.

There are a few areas of concern for our team during construction and testing of the 3D printer. One is the hot end and bed construction. These components can reach very high temperatures during and a member of our team can be burned during construction/testing. Being careful during construction is key. Testing should only be conducted after construction is completed. Another area of concern is the use of tools in construction. Each member is badged for using the tools in Donald's Garage and the Machine Shop, each member should ensure they are using each tool properly to ensure no one is injured during construction of the 3D printer. Common tools used to build printer components could include a mill, drill press, and other pieces of equipment. Most common tools that will be used to construct the printer are screwdrivers, hammers, wire cutters/strippers, and soldering tools if necessary.

### **5.3. TEST/EVALUATION PLAN**

Table 4: Customer requirements and constraints test procedures

<b>Customer requirement / constraint</b>	<b>Test procedure</b>
Achieve a deflection of less than 0.4 mm on XY linear motion system. If desired deflection not achieved, choose stronger extrusion	Using a fully assembled carriage with extruder, the midspan deflection will be measured using a precision dial indicator
Saving at least 40% power through localized heating	We will calculate our power usage through a regular heated bed that would take up the whole print bed. Then we will calculate the power saved with our localized heating system.
Layer height up to 0.4 mm	Using a combination of our stepper motor and our threaded rods, the team will be able to calculate what is the smallest layer height we can achieve.
Produce parts consistently and accurately	The will print the same benchmark part 10 times and then compare quality to see how consistent and repeatable our printer is.
Print speed of at least 120 mm/s	Using the latest and most technologically advanced motors paired with the ED3 Titan Aero we will test the speed and quality of our printer to see if we can achieve speeds up to 120 mm/s, almost double of existing average speeds.

### **5.4. PROJECT DELIVERABLES**

#### First Semester

- Research
- Preliminary Design Report, with associated modeling and analyses
- Critical Function Prototype
- Assembly drawings
- Bill of Materials and cost estimates

#### Second Semester

- Final Design Report including test results
- One working prototype that meets customer requirements
- Full set of engineering drawings
- Brief user instructions

## **5.5. SCHEDULE**

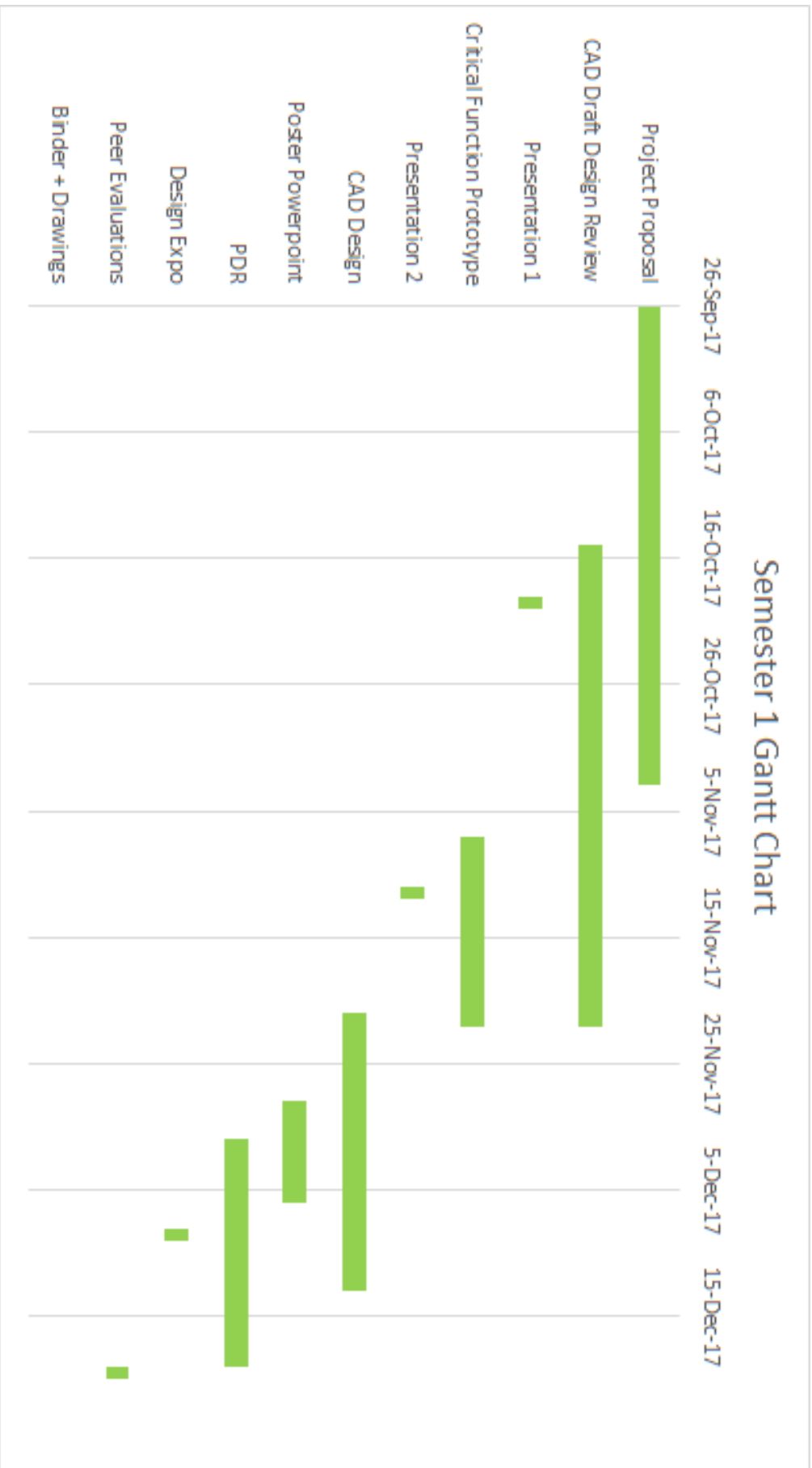
All of the milestones determined in the proposal were hit during the semester. The purpose of semester one was to research and design a low cost and efficient 3D printer. This was achieved using Solid Works and heled the project a lot during the second semester. With the design done, all that was left to do is to buy every component that we had included in the design carefully, making sure by calculations that they all met the requirements and that although the prices were low, they could work for a high quality printer.

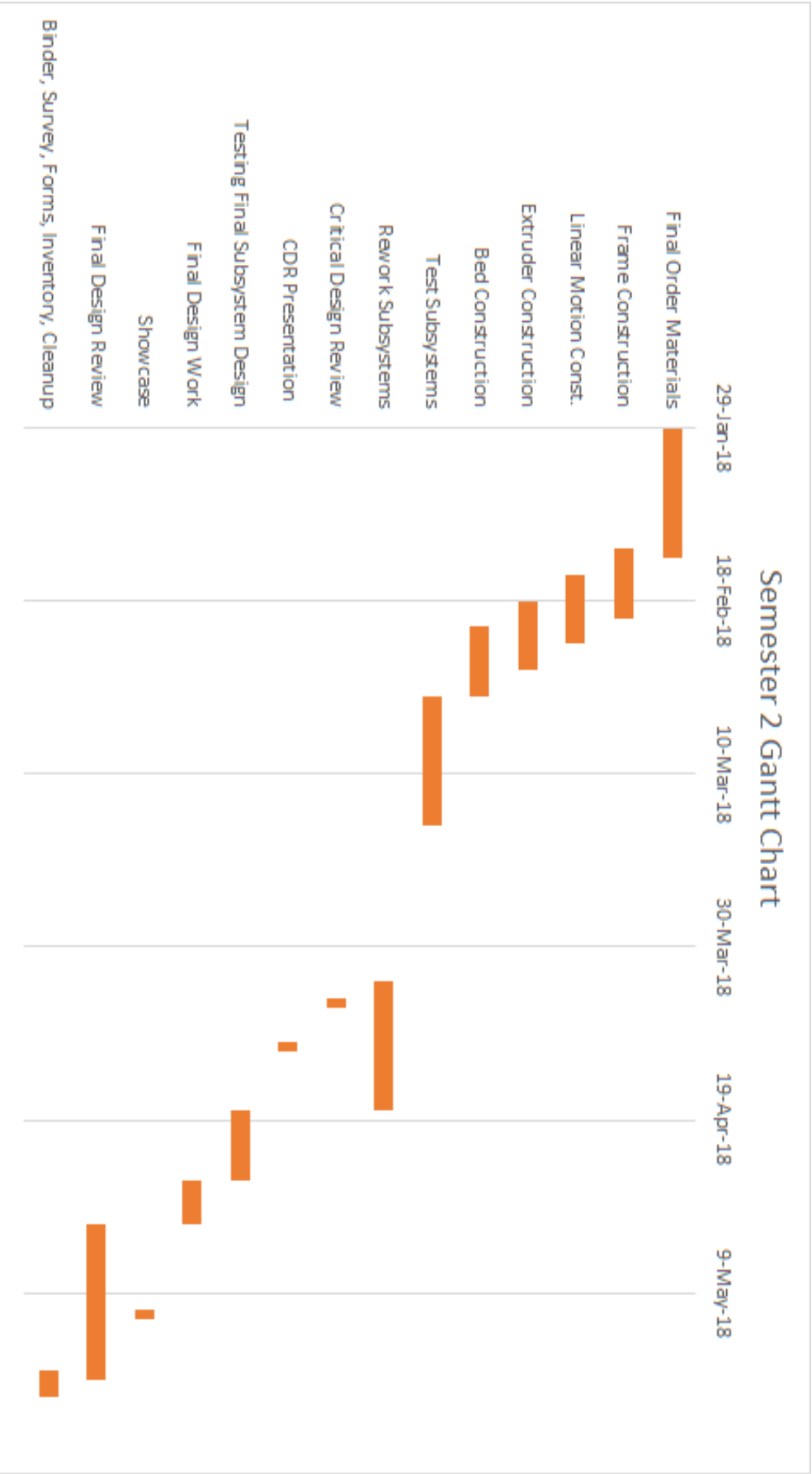
On the second semester the goal was to work quickly in the beginning and have most of the subsystems constructed early because some of the parts that were needed come all the way from China and can take a few months to arrive. As seen in the second semester chart many of the subsystem constructions overlap. This is because some systems require the construction of other. For instance, the XY linear motion system requires that the frame be done because the design clearly shows that the linear motion system rests on frame directly, this is why the outside frame was the first thing that was built on the second semester.

Construction of linear motion systems is tricky because of the perfection needed to assemble them, so the timeline was a bit extended on that part but thanks to how fast the project developed, there was enough time to work on the alignment of the linear motion. The next figure shows the state of the printer after only a week of work on the second semester.



Figure 42: Frame





## 5.6. BUDGET

Subsystem	Material	Supplier	Cost	Quantity	Shipping	Subtotal	Priority
Extruder	E3D Volcano extruder + hot end	E3D-online	115	1	0	115	Medium
Frame	Aluminum extrusions (L= 3ft=914.4mm)	misumi	24.99	4	1	100.96	High
	Aluminum extrusions (L=2.5ft=762mm)	misumi	19.99	6	1	120.94	High
	Corner attachments	misumi	23.5	4	1	95	High
	Corner brackets	misumi	0.63	16	1	11.08	High
	Acrylic sheeting for enclosure	Home depot	29.99	4	0	119.96	Low
	Aluminum extrusions (40x40mm L=2.5 ft)	misumi	24.99	3	1	74.97	High
	Various fasteners	Various retailers	100	1	1	100	High
Bed	Aluminum plate (2x2)	onlinemetals	49.99	1	16.94	66.93	High
	Water jet spider plate	Elite water jet	95	1	0	95	Medium
	Dual zone silicone rubber heater bed	Ali Express	74.99	1	0	74.99	Low
	Glass bed	dullesglass	49.99	1	14.99	64.98	Low
Z-axis	Lead screw	amazon	19	2	0	38	High
	Slide screw	ebay	20	2	0	40	High
	Guide rail	ebay	10.2	4	0	40.8	High
	linear bearing	VXB	5	4	0.92	20.92	High
	Nema 17 motor	reprapchampion	8.5	1	3.3	11.8	Medium
	20mm X 30" linear shafts	Amazon	24	4	0	96	High
	PLA and ABS material for prints	pushplastic	39.99	1	0	39.99	Low
	LMF20UU Flange bearing (x4)	Mcmaster	10	4	0	40	High
	1/2" X 30" ACME lead screw	Amazon	16.99	2	0	33.98	High
X-axis	Belt	Amazon	6.39	1	0	6.39	High
	Nema 17 motor	reprapchampion	8.5	1	3.3	11.8	Medium
	MGN15 linear guides	Amazon	155	1	0	155	High
Y-axis	Aluminum extrusions (L= 3ft=914.4mm)	misumi	7.22	1	1	8.22	High
	low profile carriage	grainger	35	1	0	35	High
	Nema 17 motor	reprapchampion	8.5	1	3.3	11.8	Medium
	Bearing wheels	amazon	10	2	0	20	Medium
Electronics	Wiring	newegg	16.99	1	2.61	19.6	Low
	Rambo v1.3 Board	ultimachine	170	1	0	170	Medium
	LCD screen and adaptor	amazon	99	1	0	99	Low
	24V Power supply	Amazon	20	1	0	20	High
	Inductive sensor	Amazon	9	1	0	9	Medium
	24V Fans	Amazon	4.99	4	0	9.98	Medium
	16gb SD card	Amazon	4.99	1	0	4.99	Low
						<b>TOTAL</b>	<b>\$ 1,982.08</b>

Table 5: Large Scale Low Cost 3D Printer Budget.

The University of San Diego gave this project a first budget of \$1000 and with it, the printer was designed and built, but later on when the machine was working and the Senior Design Project manager saw the development of the printer, the university decided to give \$1000 more to this project being a total of \$2000 for the whole machine. With this new budget the printer was then improved by changing some parts like its electronics, and also adding some small gadgets that were not needed for the printer to work but made it more usable and better looking like the LCD screen.

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