Université Mohamed Khider de Biskra
Faculté des Sciences et de la Technologie
Département de génie électrique

MÉMOIRE DE MASTER

Sciences et Technologies
Électromécanique
Électromécanique

Réf. : ……………………

Présenté et soutenu par :

HADEF Mohamed Wassim

Le : 10/07/2019

Conception et realisation d'une Imprimante 3D

Jury :

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signature

Avis favorable de l'encadreur :
MESSAOUDI abdelhamid

Avis favorable du Président du Jury

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Cachet et signature

Dedication

Thank you Allah for giving me the ability to write and think ,the strength to believe, the patience to go to the end of my dreams and the joy of the lifting my hands to the heaven and say
" Al Hamdou Li Allah "
I dedicate this work to my parents who gave me life the symbol of tenderness, who sacrifice for my happiness and success, school of my childhood and my education
Shall God protect them, I hope they are proud of me
To the genius Mohamed Sami, the Star Mounir, my second soul Mahdi
and his small family
To Melina Leila and Noursine Ezohra
To my dear wife and my lovely children in shaa allah
To all my grand family
To all my friends
To my beloved Hnya which lives now in my first made 3d printer with its kittens
To All those who are dear to me

Thanks

Many thanks to Allah, the all-powerful who gave me the strength and the courage to reach my goals

I would like to thank all those who helped me from near or far and during all my work to realize this project

I would also like to thank my family for their love and support

Department of Electrical Engineering and the well-educated teachers who work from their hearts for their students

To my former who gave his best

Thank you so much

At the same time, I thank the members of the jury who have agreed to consider and evaluate my work and participate in my presentation

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General Introduction

This project aims to introduce the conception of a 3D printer as well as the actual realization of this machine.

The concept of additive manufacturing, or more commonly known as 3D printing, is leading to an other industrial revolution, 3D printers today allow unlimited realization of objects in a variety of fields.

It has appeared during the last three decades, since then applications of 3d printing technology has evolved in several areas mainly "commercial, social, medicine, space, aeronautics, industry and many more.

Thus, as part of our end-of-studies project we have implemented a functional model of a 3D printer that uses the FFF technology: Throughout this work, we have outlined all the steps necessary for the design and construction of such a machine.

Before building this machine, we will first go through a brief historical overview of 3d printing, basic definitions, applications, then we well see different state of the art 3d printer technologies.

After that we will pick a mechanism for our machine, then we will explore the majority of its components and some close details about each.

Furthermore, we will explore some most common computer aided design software, in order to use one of them to make a concept of our machine, which would help us gain a good idea of what the end result might look like.

Finally, we will turn the concept of this machine into reality, using available tools and resources, we will discuss in close details every step we make during the construction of this machine, in addition to the problems that we might encounter

After finishing the build of our machine, we will actually use it to fabricate a part that will be used to improve the printer itself.

Therefore the work this project will be divided into four chapters. The first chapter presents a general study of 3D printing technology, including the history of 3d printing and some concept on rapid prototyping, and a general view of the different techniques and processes that are used, which allows us to define the 3D printing technique we will use in the framework of this project.

In the second chapter we will go through different components and parts that we should use and their roles. The Third chapter will introduce the mechanical form and concept of the 3d printer, in the fourth and last chapter, the step which we are concerned about, the phases of the realization of the 3D printer.

Finally, some printing illustrations of 3d sample models and functional tests will also be included.

Chapter 1

Generalities about 3D printing

Introduction

In this chapter we will will go through a historical overview of Digital fabrication technology, after that, we will see the basic definition of a 3D Printer, different types of 3D Printers, the process of 3D Printing and the fields in which a 3D Printer can be useful.

1.1 History of 3D printing

Digital fabrication technology is characterized by the basic physical process employed for the tangible object to be obtained. **The subtraction process** consists in removing the unnecessary material from a block to obtain the final object. The lathe is a tool that allows to remove the exceeding material from a block placed on a rotating platform. It has been used for centuries: the first hydraulic lathe is more than 500 years old, Modern lathes are more complicated and versatile; they use engines instead of human strength and can have quite a high level of automatism. However, they are based on the same principle with which our ancestors created the first vases regularly shaped. Milling machines are more modern machines, which allow the realization of complex products.[BBG17]

In order to realise an object we might use two techniques radically different from each other: **the subtractive process**, referring today to Computer Numerically Controlled (CNC) machining, and the **additive process**, concerning the Additive Manufacturing (AM) processes. which is popularly called 3D printing, technologies today are used by makers all over the world, but its inception can be traced back in the 1980s, at which time it was called Rapid Prototyping (RP). RP was conceived as a fast and more cost-effective method for prototypes realization for product development within the industry.[MR15]

Before describing 3D main technologies, we want to fix some important dates to tell shortly how 3D printing was born [pI19]:

- **In 1984** Chuck Hull invented and patented a Sterolithography Aparatus (SLA) machine. Hull went on to co-found 3D Systems, the first organization nowadays operating in 3D printing. The STL format file was born;
- **In 1986** Carl Deckard, Joe Beaman and Paul Forderhase (with other researchers) developed the ideas of Chuck Hull and filed a patent in the US for the Selective Laser Sintering (SLS);
- **In 1988** Crump patented the Fused deposition modelling which is printing with fuse material. This technique does not involve the use of laser or dust and uses fused plastic to spread in strata to create the object. Crump also founded Stratasys, another leading business in the field;
- **In 1993** was patented the Electron Beam Melting (EBM);

- **In 2005**, Mcor Technologies an Irish company starts the Paper 3D laminated printing: a machine, which superimposes sheets of paper and prints on them. The result is an additive method, which includes the use of colours, in addition the technology of the Self replicating rapid Prototyper a 3D printer which prints itself is first realised (open- source RepRap and FAB@Home projects). The RepRap Project is an abbreviation Replicating Rapid Prototyper, and it aims to develop a 3D printer, which prints on its own the majority of its own components. All the products created with this project are published with open source licences;
- **In 2006** the first SLS machine become available;
- **In 2008**, Bre Pettis, Adam Mayer, and Zach Hoekenî Smith found MakerBot Industries;
- **In 2011** the first 3D printed Robotic Aircraft and at the same year the worldís first 3D-printed Car, at the same year the first gold and silver jewelry were done using 3D printer;
- **In 2012** was the year that alternative 3D printing processes were introduced at the entry level of the market;
- **In 2013** was a year of significant growth and consolidation;

In the last three decades, a lot of new 3D printing technologies have been developed across the world and are still being developing and growing until now-days.

1.2 What is "3D Printing" ?

3D printing is the process in which the desired physical object is built, using additive processes, based on the digital file which describes the designed 3D model. generally the object is built layer by layer, each layer is a a horizontal cross-section of the 3Dmodel.[Wik19]

1.3 Definition of a 3D Printer

A 3D printer is a machine which is capable of creating three dimensional physical objects and structures using a custom material. different technologies are used by each type of 3D Printers, each one of them has its uses, advantages and disadvantages compared to other types.[Edu19]

1.4 Applications of 3D Printing

3D printing can be useful in different ways in a wide variety of fields. The origins of 3D printing in ëRapid Prototypingí were founded on the principles of industrial prototyping as a means of speeding up the earliest stages of product development with a quick and straightforward way of producing prototypes that allows for multiple iterations of a product to arrive more quickly and efficiently at an optimum solution. This saves time and money at the outset of the entire product development process and ensures confidence ahead of production tooling.[Che16]

Prototyping is still probably the largest, even though sometimes overlooked, application of 3D printing today.[Che16]

The developments and improvements of the process and the materials, since the emergence of 3D printing for prototyping, saw the processes being taken up for applications further down the product development process chain. Tooling and casting applications were developed utilizing the advantages of the different processes. Again, these applications are increasingly being used and adopted across industrial sectors.[PB17],[TM16]

Similarly for final manufacturing operations, the improvements are continuing to facilitate uptake.

Generally rapid prototyping is as shown in the following Figure:

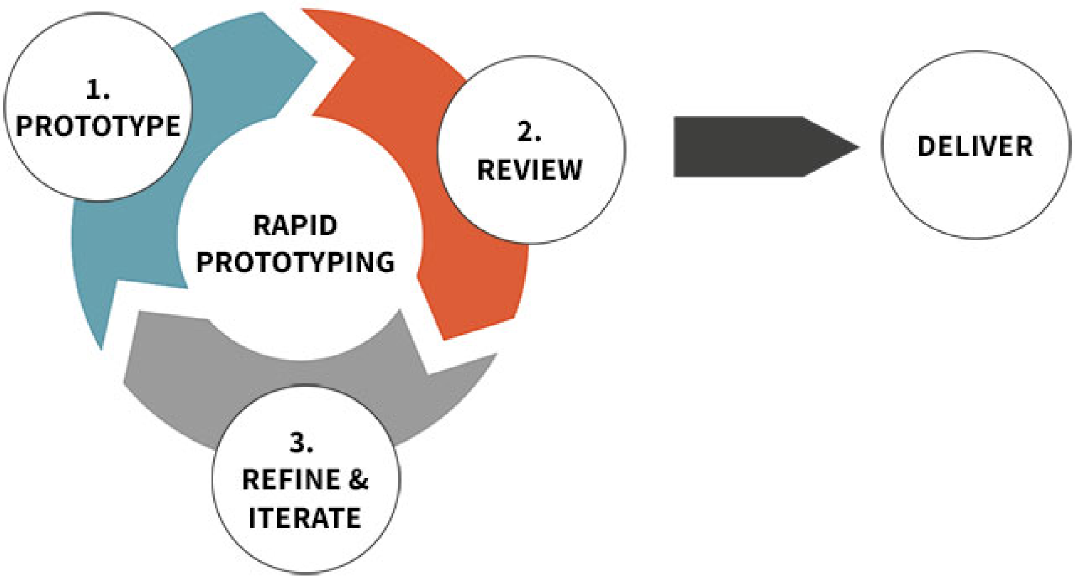

Figure 1.1: Rapid prototyping flow[pro]

In terms of the industrial vertical markets that are benefitting greatly from industrial 3D printing across all of these broad spectrum applications, the following is a basic breakdown [pI19]:

- **Medical field**

  The medical sector is viewed as being one that was an early adopter of 3D printing, but also a sector with huge potential for growth, due to the customization and personalization capabilities of the technologies and the ability to improve people's lives as the processes improve and materials are developed that meet medical grade standards.

- **Aerospace**

  Like the medical sector, the aerospace sector was an early adopter of 3D printing technologies in their earliest forms for product development and prototyping. These companies, typically working in partnership with academic and research institutes, have been at the sharp end in terms or pushing the boundaries of the technologies for manufacturing applications.

  Because of the critical nature of aircraft development, the R and D is demanding and strenuous, standards are critical and industrial grade 3D printing systems are put through their paces. Process and materials development have seen a number of key applications developed for the aerospace sector and some non-critical parts are all-ready flying on aircraft.

  High profile users include GE / Morris Technologies, Airbus / EADS, Rolls-Royce, BAE Systems and Boeing. While most of these companies do take a realistic approach in terms of what they are doing now with the technologies, and most of it is R and D, some do get quite bullish about the future

- **Automotive**

  Another general early adopter of Rapid Prototying technologies the earliest incarnation of 3D printing was the automotive sector. Many automotive companies particularly at the cutting edge of motor sport and F1 have followed a similar trajectory to the aerospace companies. First (and still) using the technologies for prototyping applications, but developing and adapting their manufacturing processes to incorporate the benefits of improved materials and end results for automotive parts.

  Many automotive companies are now also looking at the potential of 3D printing to fulfill after sales functions in terms of production of spare/replacement parts, on demand, rather than holding huge inventories.

- **Jewellery**

  Traditionally, the design and manufacturing process for jewellery has always required high levels of expertise and knowledge involving specific disciplines that include fabrication, mould-making, casting, electroplating, forging, silver/gold smithing, stone-cutting, engraving and polishing. Each of these disciplines has evolved over many years and each requires technical knowledge when applied to jewellery manufacture. Just one example is investment casting the origins of which can be traced back more than 4000 years.

  For the jewellery sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest and uptake based on how 3D printing can, and will, contribute to the further development of this industry. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for jewellery production all the way to direct 3D printed production eliminating many of the traditional steps, 3D printing has had and continues to have a tremendous impact in this sector.

- **Design**

  Mechanical designers are engaging with 3D printing in many different ways to explore form and function in ways previously impossible. This is a highly charged sector that is increasingly finding new ways of working with 3D printing and introducing the results to the world.

- **Architecture**

  Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD, BIM or other digital data that architects use. Many successful architectural firms, now commonly use 3D printing (in house or as a service) as a critical part of their workflow for increased innovation and improved communication.

  More recently some visionary architects are looking to 3D printing as a direct construction method. Research is being conducted at a number of organizations on this front, most notably Loughborough University, Contour Crafting and Universe Architecture.

1.5 Types of 3D printing technologies [JJ18],[KS16]

1.5.1 Material Extrusion

Material extrusion is a 3D printing process where a filament of solid thermoplastic material is pushed through a heated nozzle, melting it in the process. The printer deposits the material on a build platform along a predetermined path, where the filament cools and solidifies to form a solid object.

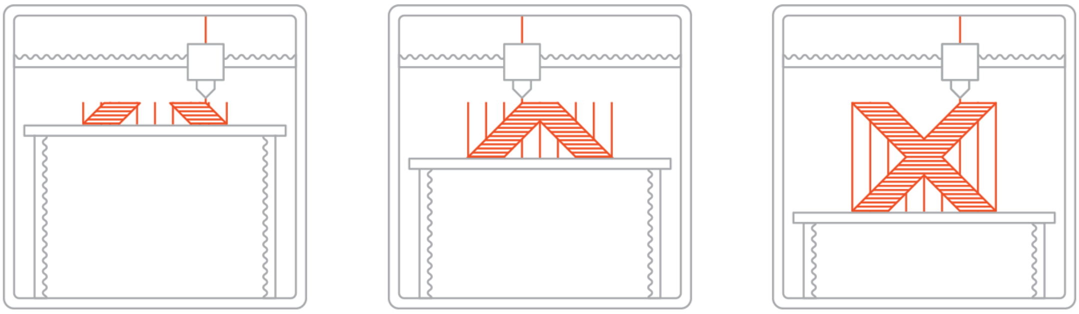

Figure 1.2: 3D Printing Process Material Extrusion based [All19]

- **Types of 3D Printing Technology:**Fused Deposition Modeling (FDM), and also called Fused Filament Fabrication (FFF).
- **Materials:** Thermoplastic filament (PLA, ABS, PET, TPU).
- **Dimensional Accuracy:** ±0.5 mm.
- **Common Applications:** Electrical housings; Form and fit testings; Jigs and fixtures; Investment casting patterns.
- **Strengths:** Best surface finish; Full color and multi-material available.
- **Weaknesses:** Brittle, not sustainable for mechanical parts; Higher cost than SLA/DLP for visual purposes.

1.5.1.1 Fused Deposition Modelling (FDM)

This is the most commonly known and easily accessible 3D printing technologies across the world. It operates on the principle of material extrusion. A solid material in the form of a filament (wire) is extruded with the help of an extruder and melted and then the print-head deposits the melted material, through a nozzle, onto a build platform. Commonly, the nozzle moves in an X-Y direction to traces out the geometry of the design and deposits one layer worth of material.

After this, the build platform moves down in the Z-direction. The distance equivalent to one layer height and the deposition (printing) resumes for the second layer. This entire process repeats and continues until the complete object is created/formed.

FDM technology is mostly used for polymer, ceramics and composite material 3D printing. A few companies are exploring metal 3D printing through this technology and Desktop Metal has successfully created a metal extrusion 3D printing product.

Figure 1.3: The new Ultimaker S5 3D Printer [typ18]

1.5.1.2 Bound Metal Deposition (BMD)

Bound Metal Deposition (BMD) is an extrusion-based 3D printing technology developed by Desktop Metal, where metal components are constructed by extrusion of a powder-filled thermoplastic media. Bound metal rods metal powder held together by wax and polymer binder are heated and extruded onto the build plate, shaping a part layer-by-layer. Once printed, the binder is removed via the debind process, and then sintered causing the metal particles to densify.

BDM technology most commonly uses metallic alloys such as stainless steels, tool steels, and other metals such as refractory metals, cemented carbides, and ceramics.

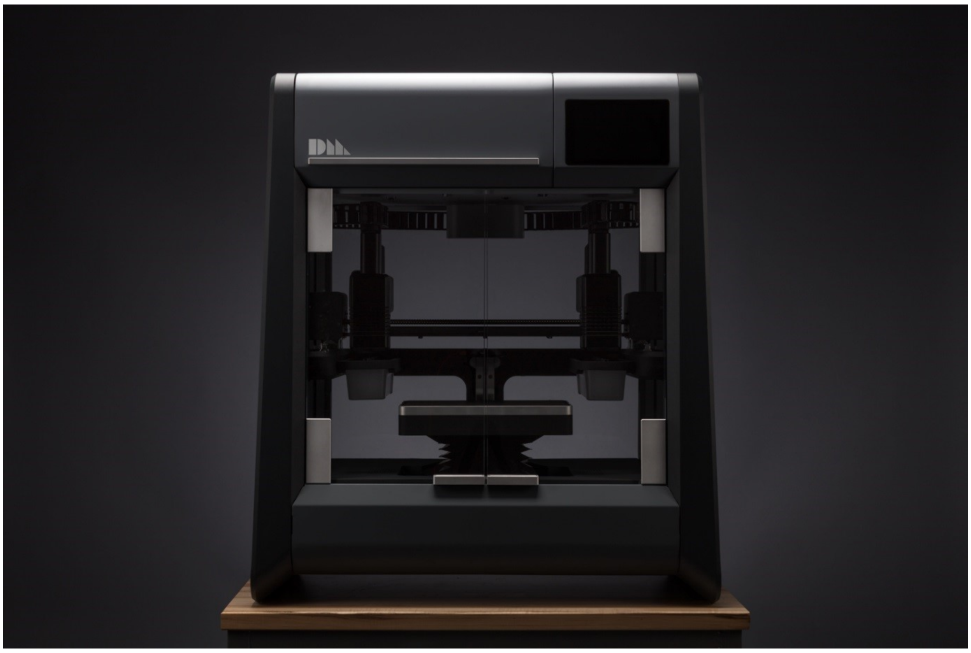

Figure 1.4: Bound Metal Deposition technology[typ18]

1.5.2 VAT Photopolymerisation

Vat Polymerization is a 3D printing process where a photo-polymer resin in a vat is selectively cured by a light source. The two most common forms of Vat Polymerization are SLA (Stereolithography) and Digital Light Processing (DLP).

The fundamental difference between these types of 3D printing technology is the light source they use to cure the resin. SLA printers use a point laser, in contrast to the voxel approach used by a DLP printer.

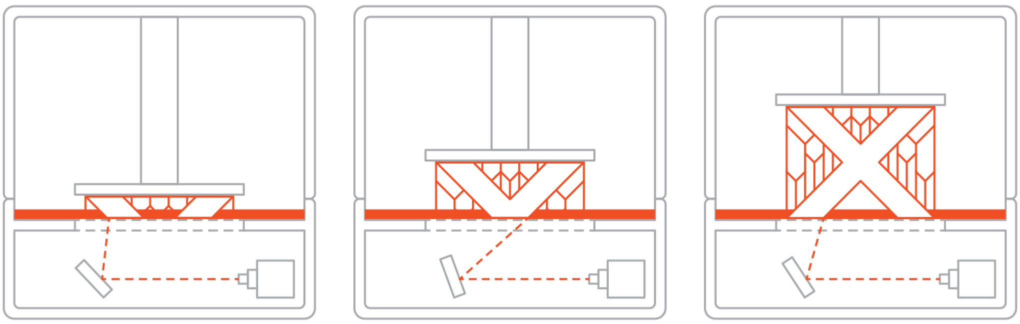

Figure 1.5: 3D printing process VAT Photopolymerisation based [All19]

- **Types of 3D Printing Technology:** Stereolithography (SLA), Direct Light Processing (DLP).

- **Materials:** Photopolymer resin (Standard, Castable, Transparent, High Temperature).
- **Dimensional Accuracy:** ±0.5 mm.
- **Common Applications:** Injection mold-like polymer prototypes; Jewelry (investment casting); Dental applications; Hearing aids.
- **Strengths:** Smooth surface finish; Fine feature details.
- **Weaknesses:** Brittle, not suitable for mechanical parts.

1.5.2.1 Stereolithography Apparatus (SLA)

Stereolithography Apparatus (SLA) was the first ever patented 3D printing technology. It is one of the fastest growing 3D printing technologies in the world. The SLA printers use photo-sensitive liquid resins as materials which are cured (hardened) on exposure to UV-laser.

A VAT holds the liquid resin and the build platform (bed) moves in Z-direction. The bed is then dipped in the resin and a laser, situated below the vat, is flashed on the interface layer to cure (harden) it. The laser traces the geometry of the design in X-Y direction and the complete layer is cured. After this the bed moves up by a distance equivalent to one-layer height and the process is repeated. This process continues until the entire object is formed.

Figure 1.6: SLA 3D Printer[typ18]

1.5.2.2 Digital Light Processing (DLP)

Digital Light Processing (DLP) 3D printing technology is quite similar to Stereolithography (SLA) 3D printing technology and also uses liquid photosensitive resins. The major difference between both these technologies is in the use of the light source and this defines the quality of product printed on both the machines. DLP technology uses a digital projector screen to flash a single image of each layer. This means a single layer of printing is completed in a single flash. Whereas in an SLA printing, a laser traces the geometry by following the coordinates. As a result, DLP is a faster as compared to SLA.

DLP technology uses resins similar to those used in Stereolithography Apparatus (SLA). Most of these resins can be used interchangeably but that is not recommended by printer manufacturers.

Figure 1.7: DLP 3D Printer [typ18]

1.5.3 Powder Bed Fusion (Polymers)

Metal Powder Bed Fusion is a 3D printing process which produces solid objects, using a thermal source to induce fusion betwen metal powder particles one layer at a time.

Most Powder Bed Fusion technologies employ mechanisms for adding powder as the object is being constructed, resulting in the final component being encased in the metal powder. The main variations in metal Powder Bed Fusion technologies come from the use of different energy sources; lasers or electron beams.

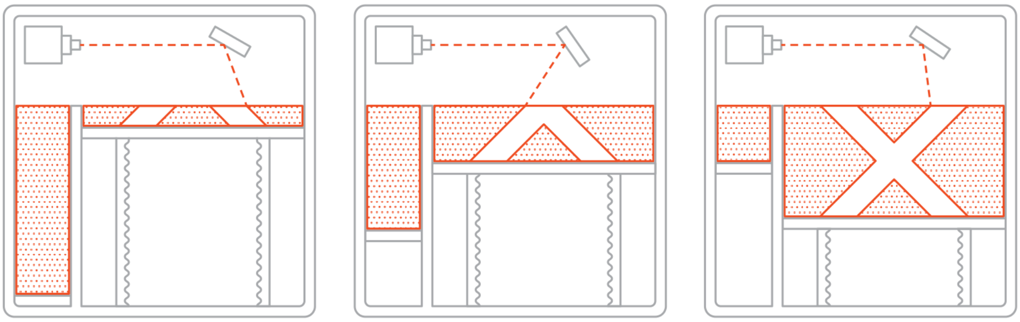

Figure 1.8: 3D printing process Powder Bed Fusion (Polymers) based [All19]

- **Types of 3D Printing Technology:** Selective Laser Sintering (SLS).
- **Materials:** Thermoplastic powder (Nylon 6, Nylon 11, Nylon 12).
- **Dimensional Accuracy:** ±0.3 mm.
- **Common Applications:** Functional parts; Complex ducting (hollow designs); Low run part production.
- **Strengths:** Functional parts, good mechanical properties; Complex geometries.
- **Weaknesses:** Longer lead times; Higher cost than FFF for functional applications.

1.5.3.1 Laser-Based

- **Selective Laser Sintering (SLS)**

  This is one of the most popular powder-based 3D printing technologies. It uses powdered polymer materials for creating complex objects. The most special fact about the Selective Laser Sintering is that they do not require support materials and hence are able to create some of the most complex models compared to any other technology.

  The process starts with the build chamber being heated just below the melting temperature of the powdered material. On reaching the preset temperature, the roller brings the first layer of material and spreads it in the build chamber. Once the layer is spread the laser springs into action. The powerful CO2 laser is activated and falls on the scanning system. The scanning system directs the laser to the accurate coordinates and traces the desired geometry on the first layer of the material. As the laser falls on the fine particles, they are heated above its melting temperature and adjacent particles fuse together to form a bond. This process is also called as Powder Bed Fusion or Sintering. This completes printing of the first layer and is repeated until the complete object is formed.

  SLS technology most commonly prints with only nylon materials like PA11 and PA12.

- **Direct Metal Laser Sintering (DMLS)**

  Direct Metal Laser Sintering (DMLS) 3D printing technology is exactly similar to SLS technology with the only difference being in the use of materials. SLS uses only polymer-based materials whereas DMLS uses metal materials for 3D printing.

  DMLS uses powdered materials like Stainless steels, Tool steel, Maraging steel, Cobalt-Chromium alloys, Inconel 625 and Inconel 718, Aluminium copper alloys, titanium and titanium alloys.

- **Selective Laser Melting (SLM)**

  Selective Laser Melting (SLM) is also quite similar to Direct Metal Laser Sintering (DMLS) process as this process also uses powdered metal materials but the major difference is in the fact that this technology melts the material rather than sintering it (like in the case of DMLS). As the materials are to be melted above their melting temperatures, the SLM technology is a very high-energy process. The melting can also lead to stresses inside the final product. But the SLM prints objects that are denser and stronger than DMLS.

  SLM technology prints with materials like stainless steel, tool steel, titanium, cobalt chrome, aluminium, nickel alloys, etc.

- **Selective Heat Sintering (SHS)**

  A Danish company Blueprinter first patented the Selective Heat Sintering (SHS) 3D printing technology in 2011 but it filed for bankruptcy in 2016. It is an additive manufacturing process similar to Selective Laser Sintering (SLS). The major separating factor is the heat source. While SLS uses a laser, SHS uses a thermal printhead to sinter polymer powder.

  SHS technology had a few benefits over the SLS technology like the smaller size of machines and low cost of machines (since thermal printheads are cheaper than lasers).

1.5.3.2 Electron-Based

- **Electron Beam Melting (EBM)**

  Electron beam melting (EBM) is a 3D printing technology which is akin to Selective Laser Melting (SLM). Similar to SLM, it prints parts that are dense and strong. The only difference in both the technologies is the fact that EBM uses an electron beam to melt the powder instead of the laser in case of SLM.

  EBM technology can print with a limited number of metals like titanium alloys and cobalt-chrome. It has specific applications in the aerospace industry.

1.5.3.3 Agent-Based

- **MultiJet Fusion (MJF)**

Multi Jet Fusion (MJF) is the patented technology developed by Hewlett-Packard (HP). It is a powder-bed 3D printing technology but does not use lasers to sinter or melt the material. Instead, it uses a fusing agent to fuse adjacent powder particles.

In the MJF technology, the powdered material is held in a build chamber. This chamber is heated uniformly. The fusing agent is selectively jetted through a printhead and it traces the design geometry. A second liquid, detailing agent, is jetted around the contours of this geometry to improve the part resolution. After this, a lamp passes over the chamber and it uniformly distributes heat across the material.

Multi Jet Fusion technology has significantly transformed the powder-bed technology by bringing improved accuracy, precision, and shorter lead times. Since there is no sintering or melting the technology uses low energy and the parts manufactured have higher density and better strength.

Currently, it has a very limited number of materials. PA 12 (Polyamide) is the most popular material offered by the company.

Figure 1.9: Multi Jet Fusion(MJF) [typ18]

1.5.4 Material Jetting

Material Jetting is a 3D printing process where droplets of material are selectively deposited and cured on a build plate. Using photopolymers or wax droplets that cure when exposed to light, objects are built up one layer at a time.

The nature of the Material Jetting process allows for different materials to be printed in the same object. One application for this technique is to fabricate support structures from a different material to the model being produced.

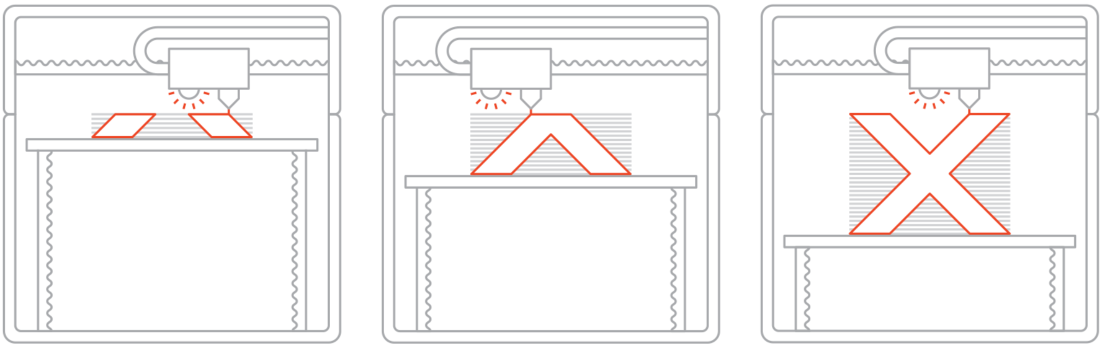

Figure 1.10: 3D printing process Material Jetting based [All19]

- **Types of 3D Printing Technology:** Material Jetting (MJ), Drop on Demand (DOD).
- **Materials:** Photopolymer resin (Standard, Castable, Transparent, High Temperature).
- **Dimensional Accuracy:** ±0.1 mm.
- **Common Applications:** Full color product prototypes; Injection mold-like prototypes; Low run injection molds; Medical models.
- **Strengths:** Best surface finish; Full color and multi-material available.
- **Weaknesses:** Brittle, not suitable for mechanical parts; Higher cost than SLA/DLP for visual purposes.

1.5.4.1 Polyjet Technology

The Polyjet technology works on a principle quite similar to two-dimensional inkjet printing technology.

In this process, the liquid material is dropped on demand or continuously through a printhead onto a build platform. It is immediately exposed to UV light which solidifies or cures the droplets to fuse them together. The droplets are as small as 16 microns. This process is continuously repeated and the model is built layer by layer.

The high resolution enables the printer to produce prints with smooth and detailed parts.

The polyjet technology uses materials like polymers and waxes as they can be used in a liquid drop form. Most importantly, full-colour and multi-material products can be easily printed/manufactured using this technology.

Figure 1.11: Polyjet 3D Printer [typ18]

1.5.4.2 NanoParticle Jetting

NanoParticle Jetting is a 3D printing technology which enables the easy production of parts with high throughput and high quality.

NanoParticle Jetting is a unique technology which manufactures parts by jetting thousands of droplets of metal (or ceramic) nanoparticles from inkjet nozzles in super-thin layers almost as fine as 10 micro m. These nanoparticles vary in size and shape and are randomly distributed on the build platform. Along with the material, a second soluble support material is also jetted in the same way. The subsequent part formed is called a ëGreen Partí and it is later sintered to enhance the mechanical properties of the final part.

NanoParticle Jetting technology can work with Ceramics and Metals.

1.5.4.3 Drop On-Demand (DOD)

The Drop-On-Demand 3D printing technology is based on MagnetoHydroDynamic (MHD)-based droplet generation. In this method, a solid metal wire is fed continuously into a heating chamber of an MHD printhead and melted to form liquid metal. This liquid metal is then electromagnetically manipulated causing a droplet to form and eject with precision from a precision ceramic nozzle. By moving the nozzle as per the design the three-dimensional objects can be formed.

This technology is patented by Vader Systems under the tradename Magnet-o-Jetô technology. This system has a very high deposition rate of around 1000 droplets per second. It also eliminates the disadvantages of the powder-bed fusion technologies for metal 3D printing.

1.5.5 Binder Jetting

Binder Jetting is a 3D printing process where a liquid bonding agent selectively binds regions of a powder bed.

Binder Jetting is a similar 3D printing technology to SLS, with the requirement for an initial layer of powder on the build platform. But unlike SLS, which uses a laser to sinter powder, Binder Jetting moves a print head over the powder surface depositing binder droplets which are typically 80 microns in diameter. These droplets bind the powder particles together to produce each layer of the object.

Once a layer has been printed, the powder bed is lowered and a new layer of powder is spread over the recently printed layer. This process is repeated until a complete object is formed.

The object is then left in the powder to cure and gain strength. Afterwards, the object is removed from the powder bed and any unbound powder is removed using compressed air.

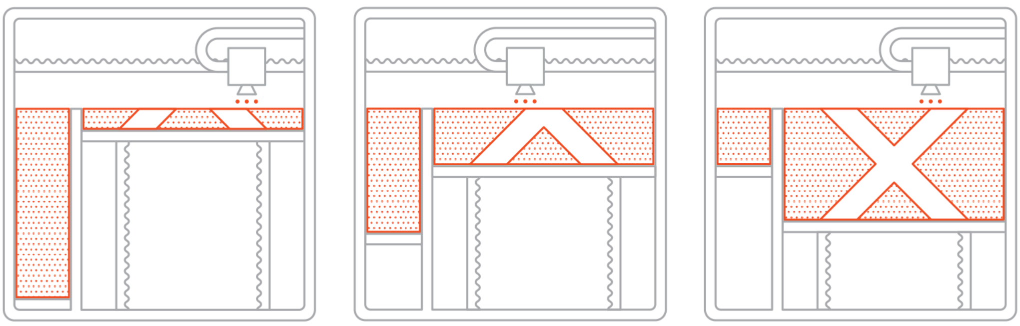

Figure 1.12: 3D printing process Binder Jetting based [All19]

- **Types of 3D Printing Technology:** Binder Jetting (BJ).
- **Materials:** Sand or metal powder: Stainless / Bronze, Full color sand, Silicia (sand casting).
- **Dimensional Accuracy:** ±0.2 mm (metal) or ±0.3 mm (sand).
- **Common Applications:** Functional metal parts; Full color models; Sand casting.
- **Strengths:** Low-cost; Large build volumes; Functional metal parts.
- **Weaknesses:** Mechanical properties not as good as metal powder bed fusion

1.5.5.1 Sand Binder Jetting

With Sand Binder Jetting devices, these are low-cost types of 3D printing technology for producing parts from sand, e.g. sandstone or gypsum.

For full color models, objects are fabricated using a plaster-based or PMMA powder in conjunction with a liquid binding agent. The printhead first jets the binding agent, while a secondary print head jets in color, allowing full color models to be printed.

Once parts have fully cured they are removed from the loose unbonded powder and cleaned. To enhance mechanical properties, parts are often exposed to an infiltrant material.

There are a large number of infiltrants available, each resulting in different properties. Coatings can also be added to improve the vibrancy of colors.

Binder Jetting is also useful for the production of sand cast molds and cores. The cores and molds are generally printed with sand, although artificial sand (silica) can be used for special applications.

After printing, the cores and molds are removed from the build area and cleaned to remove any loose sand. The molds are typically immediately ready for casting. After casting, the mold is broken apart and the final metal component removed.

The big advantage of producing sand casting cores and molds with Binder Jetting is the large, complex geometries the process is able to produce at relatively low-cost. Plus, the process is quite easy to integrate into existing manufacturing or foundry process without disruption.

1.5.5.2 Metal Binder Jetting

Binder Jetting can also be used for the fabrication of metal objects. Metal powder is bound using a polyer binding agent. Producing metal objects using Binder Jetting allows for the production of complex geometries well beyond the capabilities of conventional manufacturing techniques.

Functional metal objects can only be produced via a secondary process like infiltration or sintering, however. The cost and quality of the end result generally defines which secondary process is the most appropriate for a certain application. Without these additional steps, a part made with metal Binder Jetting will have poor mechanical properties.

The infiltration secondary process works as follows: initially metal powder particles are bound together using a binding agent to form a ìgreen stateî object. Once the objects have fully cured, they are removed from the loose powder and placed in a furnace, where the binder is burnt out. This leaves the object at around 60% density with voids throughout.

Next, bronze is used to infiltrate the voids via capillary action, resulting in an object with around 90% density and greater strength. However, objects made with metal Binder Jetting generally have lower mechanical properties than metal parts made with Powder Bed Fusion.

The sintering secondary process can be applied where metal parts are made without infiltration. After printing is complete, green state objects are cured in an oven. Next, theyíre sintered in a furnace to a high density of around 97%. However, non-uniform shrinkage can be an issue during sintering and should be accounted for at the design stage.

1.5.6 Powder Bed Fusion (Metals)

Metal Powder Bed Fusion is a 3D printing process which produces solid objects, using a thermal source to induce fusion betwen metal powder particles one layer at a time.

Most Powder Bed Fusion technologies employ mechanisms for adding powder as the object is being constructed, resulting in the final component being encased in the metal powder. The main variations in metal Powder Bed Fusion technologies come from the use of different energy sources; lasers or electron beams.

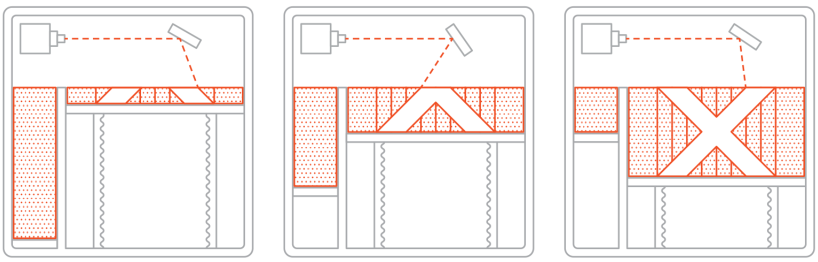

Figure 1.13: 3D printing process Powder Bed Fusion (Metals) based [All19]

- **Types of 3D Printing Technology:** Direct Metal Laser Sintering (DMLS); Selective Laser Melting (SLM); Electron Beam Melting (EBM).
- **Materials:** Metal Powder: Aluminum, Stainless Steel, Titanium.
- **Dimensional Accuracy:** ±0.1 mm.
- **Common Applications:** Functional metal parts (aerospace and automotive); Medical; Dental.
- **Strengths:** Strongest, functional parts; Complex geometries.
- **Weaknesses:** Small build sizes; Highest price point of all technologies.

1.5.6.1 Direct Metal Laser Sintering (DMLS) / Selective Laser Melting (SLM)

Both Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) produce objects in a similar fashion to SLS. The main difference is that these types of 3D printing technology are applied to the production of metal parts.

DMLS does not melt the powder but instead heats it to a point so that it can fuse together on a molecular level. SLM uses the laser to achieve a full melt of the metal powder forming a homogeneous part. This results in a part that has a single melting temperature (something not produced with an alloy).

This is the main difference between DMLS and SLM; the former produces parts from metal alloys, while the latter form single element materials, such as titanium.

Unlike SLS, the DMLS and SLM processes require structural support, in order to limit the possibility of any distortion that may occur (despite the fact that the surrounding powder provides physical support).

DMLS/SLM parts are at risk of warping due to the residual stresses produced during printing, because of the high temperatures. Parts are also typically heat-treated after printing, while still attached to the build plate, to relieve any stresses in the parts after printing.

1.5.6.2 Electron Beam Melting (EBM)

Distinct from other Powder Bed Fusion techniques, Electron Beam Melting (EBM) uses a high energy beam, or electrons, to induce fusion between the particles of metal powder.

A focused electron beam scans across a thin layer of powder, causing localized melting and solidification over a specific cross-sectional area. These areas are built up to create a solid object.

Compared to SLM and DMLS types of 3D printing technology, EBM generally has a superior build speed because of its higher energy density. However, things like minimum feature size, powder particle size, layer thickness and surface finish are typically larger.

Also important to note is that EBM parts are fabricated in a vacuum, and the process can only be used with conductive materials.

Figure 1.14: Electron Beam Melting [typ18]

The following sections will focus on the material, printing technology, 3D printing equipment and part quality issues and standards.

1.6 3D Printing Materials

Materials in additive manufacturing technology systems are defined by the fabrication processing technology. Each 3D printing technology transforms material through external heat, light, lasers and other directed energies. The ability of a materialís mechanical composition to react positively to a certain directed energy marries that material to a technology which can deliver the desired change. These material-technology partnerships will expand as materials are advanced and material chemistry explored. Advancing technologies encourages more positive material reactions, layer by layer, to directed external energies.

The mechanism of material change-unique to individual 3D printing technologies and processes-defines the material in terms of state changes, final mechanical properties and design capabilities. By extension, developments in 3D printing materials correspond with developments in 3D manufacturing; as the build process improves to encourage more positive reactions from materials, material selections will expand.

The 3D printing materials are available in different material types and states such as powder, filament, pellets, granules, resin etc. Specific material types and material properties are developed more precisely to suit the application. There are plenty of materials already available. New materials are being developed as the new applications are emerging for 3D Printing. In this section the most popular types of AM material types are reviewed.[Str15],[Cat08]

- **Plastics**

  Nylon, or Polyamide, is a strong, flexible, reliable and durable plastic material commonly used in powder form with the sintering process or in filament form with the Fusion Deposition Modeling (FDM) process. It is naturally white in color but it can be colored pre -or post-printing.

  This material can also be combined (in powder format) with powdered aluminum to produce another common 3D printing material for sintering- Alumide. ABS is another strong plastic used for 3D printing, in filament form. It is available in a wide range of colors.

  Polylactic acid or polylactide (PLA) is a biodegradable plastic material be utilized in resin format for Digital Light Processing/stereolithography (DLP/SL) processes as well as in filament form for the FDM process.

  It is offered in a variety of colors, including transparent, which has proven to be a useful option for some applications. However, it is not as durable or as flexible as ABS.

  LayWood is a specially developed 3D printing material for entry-level extrusion 3D printers. It comes in filament form and is a Wood/Polymer composite (WPC). This special filament is a composite material of recycled wood and polymer parts that can create wood-like objects that have the look, feel and even the smell of wood. It can be printed between 175-2500C. It is available in light and dark color wood.

- **Metals**

  The most common metals and metal composites are titanium, aluminum and cobalt derivatives. One of the strongest metals for 3D printing is stainless steel in powder form for the sintering/melting/electron beam melting processes.

  It is naturally silver, but can be plated with other materials to give gold or bronze effect applications across the jewelry sector.

- **Ceramics**

  Ceramics are a relatively new group of materials that can be used for 3D printing with various levels of success. The ceramic parts need to undergo post-processing processes same as any ceramic part made using traditional methods of production namely firing and glazing.

- **Paper**

  Paper-based 3D printers use the proprietary Simple DirectMedia Layer (SDL) process. 3D printed models made with paper are safe, environmentally friendly, and easily recyclable and require no post-processing.

- **Bio Materials**.

  Material from biological origin instead of fossil fuels. There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical (and other) applications.

  Living tissue is being investigated at a number of leading institutions with a view to developing applications that include printing human organs for transplant, as well as external tissues for replacement body parts.

- **Food**

  Experiments with extruders for 3D printing food substances have increased dramatically over the last couple of years. Chocolate is the most common (and desirable). There are also printers that work with sugar and some experiments with pasta and meat.

  Looking to the future, research is being undertaken, to utilize 3D printing technology to produce finely balanced whole meals.

- **Other**

  Objet Connex 3D printing platform printing process combines various materials and specified concentrations to form new materials with the required properties. Up to 140 different Digital Materials can be realized from combining the existing primary materials in different ways.

1.7 Choice of 3D Printer technology

After understanding how the different technologies work, as well as the areas of application, we will start making our printer. The chosen technology is the Fusion Filament Fabrication (FFF), because it is the most accessible and with the lowest cost.

In addition to the reasons mentioned earlier, Fusion Filament Fabrication is the most used 3D printing technology nowadays. Bellow is a figure that shows world wide statistic of the most used 3D printing technologies as of July 2018. Fused Filament Fabrication has 69%

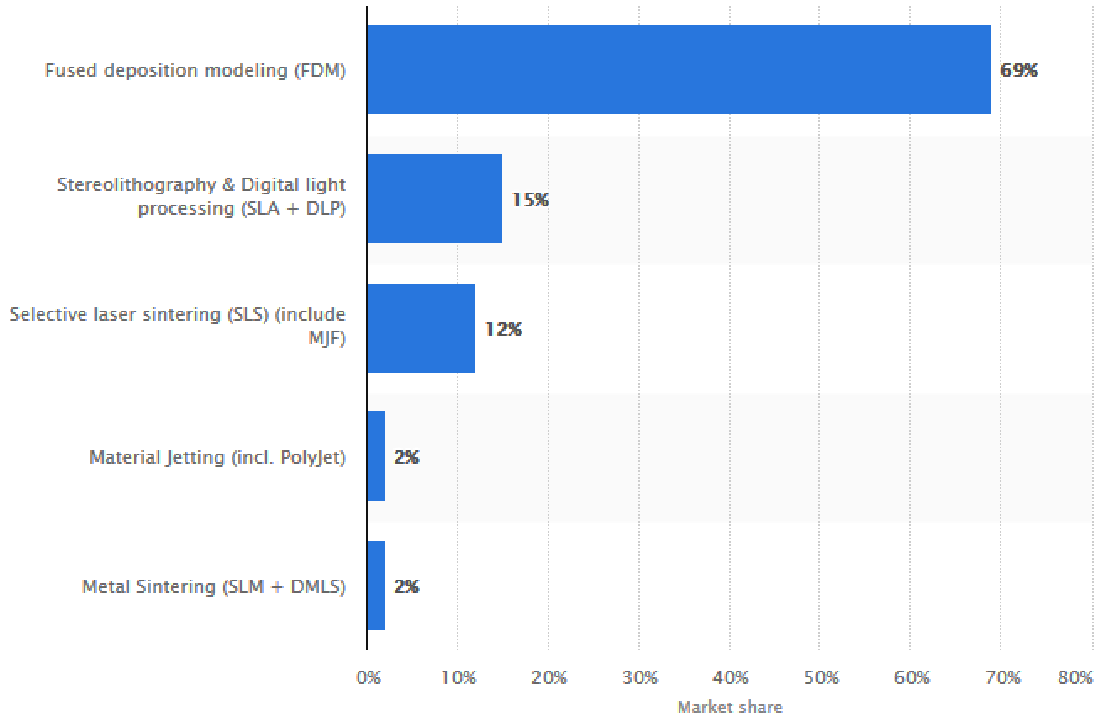

Figure 1.15: Worldwide most used 3D printing technologies, as of July 2018[sta]

Conclusion

In this chapter we've seen different types of technologies used by 3D printers in a wide variety of fields.

on the following chapter we will see different models of 3D printers that use Fusion filament fabrication and pick one model to realize.

Chapter 2

Fused Filament Fabrication 3D Printer

Introduction

In this chapter we will see some most popular fusion filament fabrication 3D printers and pick a model from them to be realized, we will also see how does it work and the details about each of its components.

2.1 Fusion filament fabrication 3D printers

In order to print a 3D object using fused filament fabrication technology, the printing head should be able to extrude material on a 2d plane as a layer, and also on top of this layer, therefore motion on the three axis X, Y and Z is required, in what follows a list of fusion filament fabrication 3D printers.

2.2 Mechanism choice of the 3D printer

To achieve the desired motion of the printing head, we have to choose a mechanism that allows fast and accurate motion, and here is a suggested list of mechanisms that we find interesting and which allow this required motion

2.2.1 Common types of FFF 3D Printers [3dt]

2.2.1.1 Cartesian 3D printer

Cartesian 3D printers are the most common FDM 3D printer found on the market. Based on the Cartesian coordinate system in mathematics, this technology uses three-axis: X, Y, and Z to determine the correct positions and direction of the print head. With this type of printer, the printing bed usually moves only on the Z-axis, with the print head, working two-dimensionally on the X-Y plane.

2.2.1.2 Delta

These printers are being seen more and more on the FFF 3D printing market, with a recent addition that was developed by two Swiss students, which consisted of a six-axis 3D printer that was based on the Delta technology. These machines operate with Cartesian coordinates. This involves a round printing plate that is combined with an extruder that is fixed at three triangular points. Each of the three points then moves up and down, thereby determining the position and direction of the print head.

2.2.1.3 Polar

Polar 3D printers' positioning is not determined by the X, Y, and Z coordinates, but by an angle and length. This means that the plate rotates and moves at the same time, with the extruder moving up and down.

2.3 choosing a mechanism

After exploring different types of mechanisms that are used by fused filament fabrication 3D Printers, we decided to pick a mechanism that allows rapid movement for the printing head, the H-bot mechanism as shown in Figure 2.1 allows movements of the printing on the X and Y axis with two stationary motors, it is categorized as a cartesian type of 3D Printers, compared to some other cartesian printers, it doesn't need to move the extra mass of one of the motors.

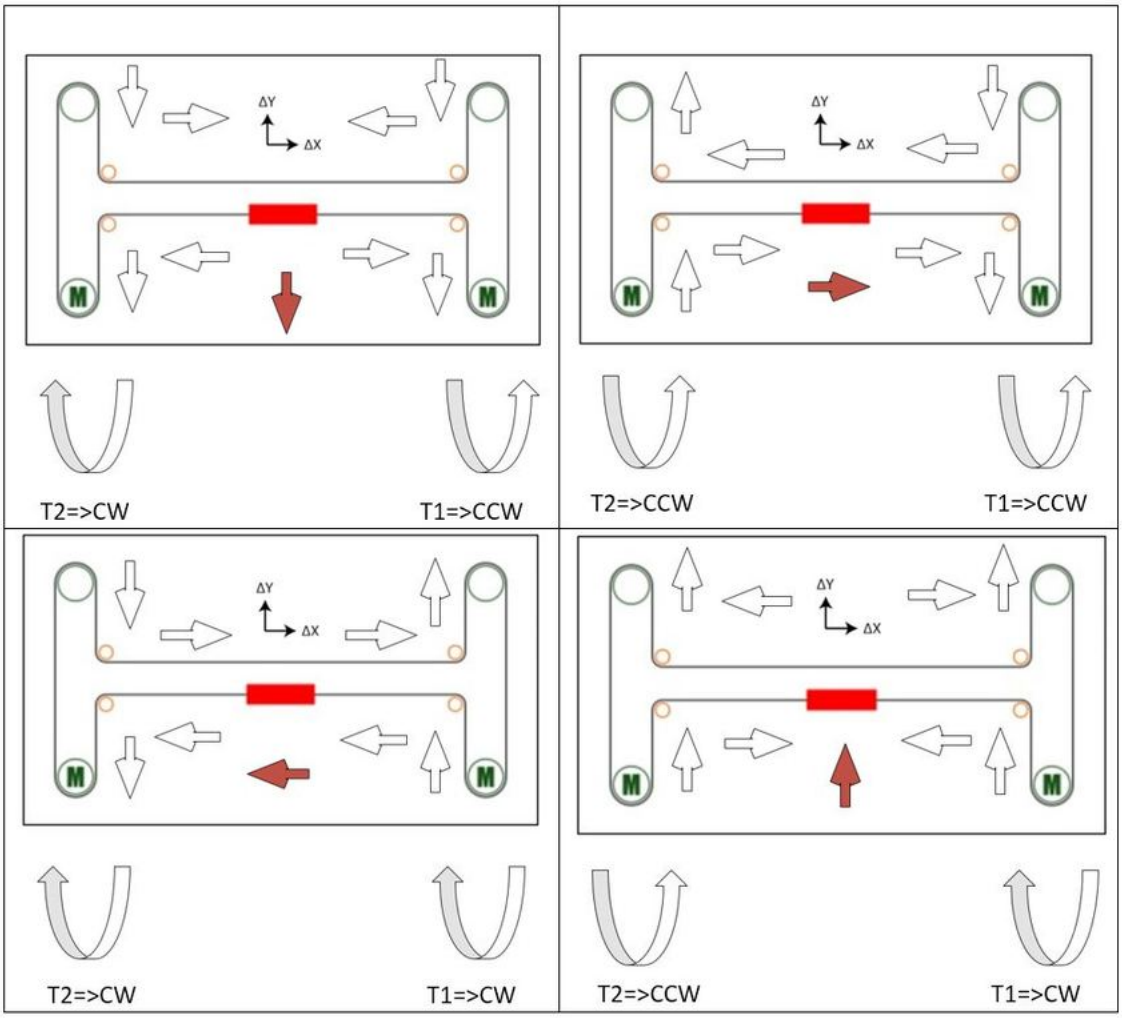

Figure 2.1: Movement analysis in the H-bot mechanism [hbo]

2.4 Stepper Motors and Drivers[stpc]

The stepper motor is used to achieve precise positioning via digital control. The motor operates by accurately synchronizing with the pulse signal output from the controller to the driver. Stepper motors, with their ability to produce high torque at a low speed while minimizing vibration, they are ideal for applications requiring quick positioning over a short distance.

2.4.1 Accurate Positioning in Fine Steps

A stepper motor rotates with a fixed step angle, just like the second hand of a clock. This angle is called "basic step angle". Oriental Motor offers stepper motors with a basic step angle of 0.36°, 0.72°, 0.9° and 1.8°.

2.4.2 Utilizing Hybrid Stepper Motor Technology

A hybrid stepper motor is a combination of the variable reluctance and permanent magnet type motors. The rotor of a hybrid stepper motor is axially magnetized like a permanent magnet stepper motor, and the stator is electromagnetically energized like a variable reluctance stepper motor. Both the stator and rotor are multi-toothed. A hybrid stepper motor has an axially magnetized rotor, meaning one end is magnetized as a north pole, and the other end a south pole. Toothed rotor cups are placed on each end of the magnet, and the cups are offset by half of a tooth pitch.

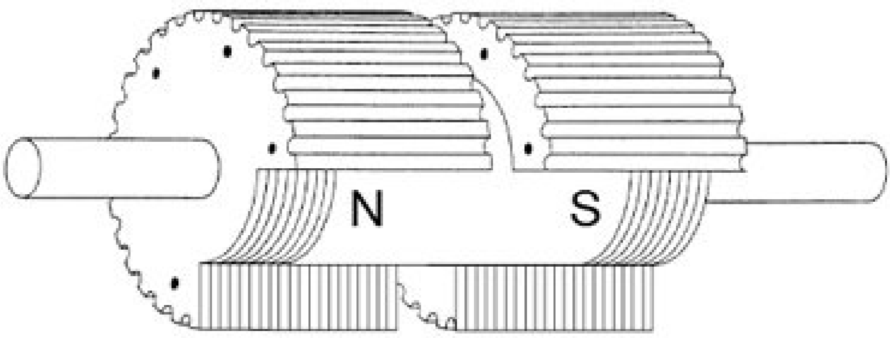

Figure 2.2: Hybrid stepper motor rotor

2.4.3 Easy Control with Pulse Signals

A system configuration for high accuracy positioning is shown below. The rotation angle and speed of the stepper motor can be controlled with precise accuracy by using pulse signals from the controller.

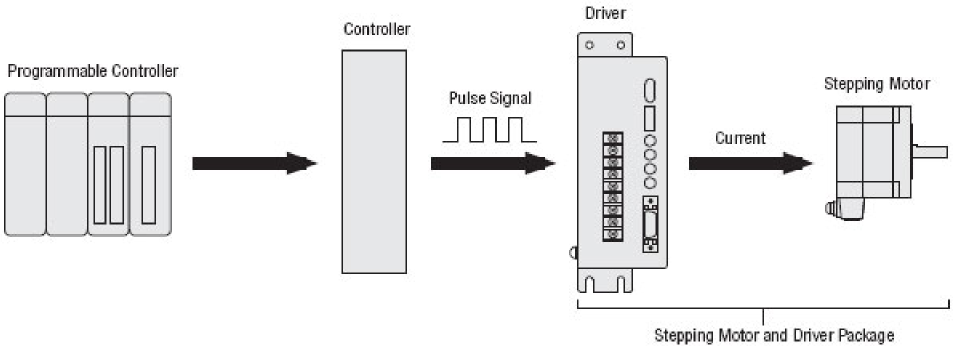

Figure 2.3: Stepper motor control

2.4.4 Pulse Signal

A pulse signal is an electrical signal whose voltage level changes repeatedly between ON and OFF. Each ON/OFF cycle is counted as one pulse. A command with one pulse causes the motor output shaft to turn by one step. The signal levels corresponding to voltage ON and OFF conditions are referred to as "H" and "L" respectively.

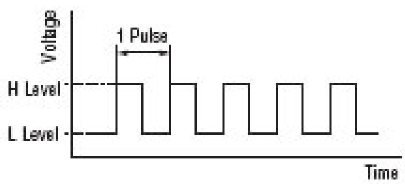

Figure 2.4: Pulse Signal

2.4.5 Number of Steps and Angle of Rotation are proportional

The amount the stepper motor rotates is proportional to the number of pulse signals (pulse number) given to the driver. The relationship between the stepper motor's rotation (rotation angle of the motor output shaft) and pulse number is expressed as follows:

Figure 2.5: The relationship between the stepper motor's angle of rotation and pulse number

2.4.6 Speed of the stepper motor is proportional to the Pulse Speed

The speed of the stepper motor is proportional to the speed of pulse signals (pulse frequency) given to the driver. The relationship of the pulse speed [Hz] and the motor speed [r/min] is expressed as in Figure 2.6

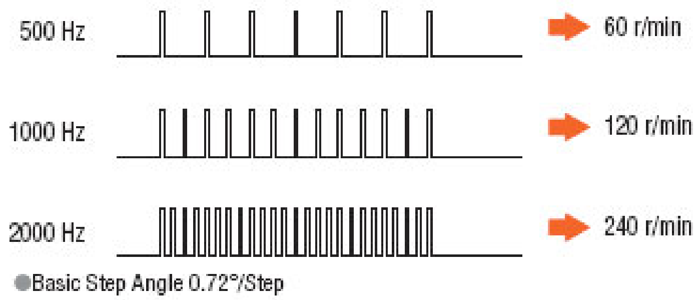

Figure 2.6: The relationship between Rotation Speed and Pulse Speed

2.4.7 Generating High Torque with a Compact Body

The stepper motors generate high torque with a compact body. These features give them excellent acceleration and response, which in turn makes these motors well-suited for torque-demanding applications where the motor must start and stop frequently. To meet the need for greater torque at low speed, Oriental Motor also has geared motors combining compact design and high torque.

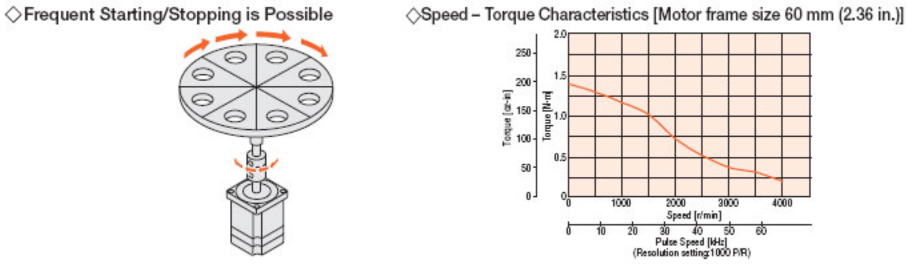

Figure 2.7: Speed torque characteristics

2.4.8 Holding Torque

Stepper motors continue to generate holding torque even at standstill. This means that the motor can be held at a stopped position without using a mechanical brake. Once the power is cut off, the self-holding torque of the motor is lost and the motor can no longer be held at the stopped position in vertical operations or when an external force is applied. In lift and similar applications, use an electromagnetic brake type.

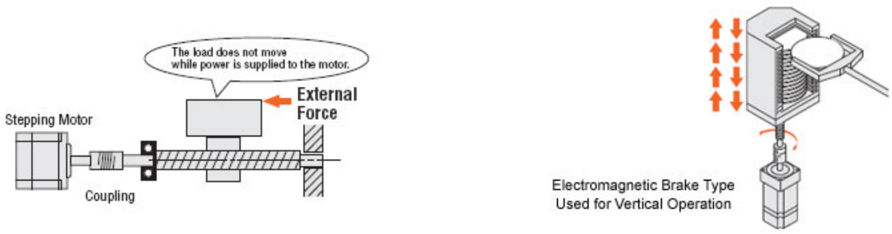

Figure 2.8: Usage examples of holding torque

2.4.9 Full stepping, half stepping and micro-stepping[fhm]

Stepper drives control how a stepper motor operates, there are three commonly used excitation modes for stepper motors, full step, half step and microstepping. These excitation modes have an effect on both the running properties and torque the motor delivers.

A stepper motor converts electronic signals into mechanical movement each time an incoming pulse is applied to the motor. Each pulse moves the shaft in fixed increments. If the stepper motor has a 1.8° step resolution, then in order for shaft to rotate one complete revolution, in full step operation, the stepper motor needs to receive 200 pulses to complete one full rotation, by turning 1.8° on each step.

There are two types of full step excitation modes. In one-phase on - full step, Fig1, the motor is operated with only one phase energized at a time. This mode requires the least amount of power from the driver of any of the excitation modes.

In two-phase on - full step, Fig2, the motor is operated with both phases energized at the same time. This mode provides improved torque and speed performance. Two-phase on provides about 30% to 40% more torque than one phase on, however it requires twice as much power from the driver.

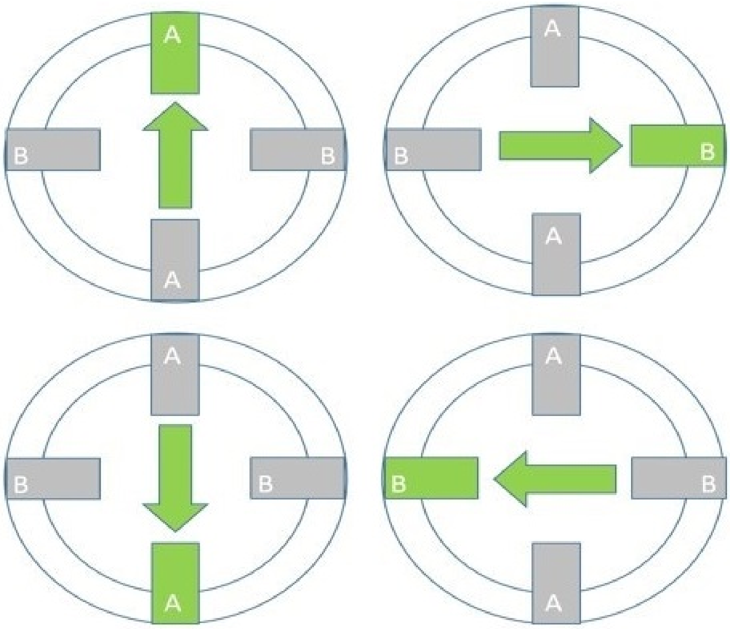

Figure 2.9: One phase on, Full step

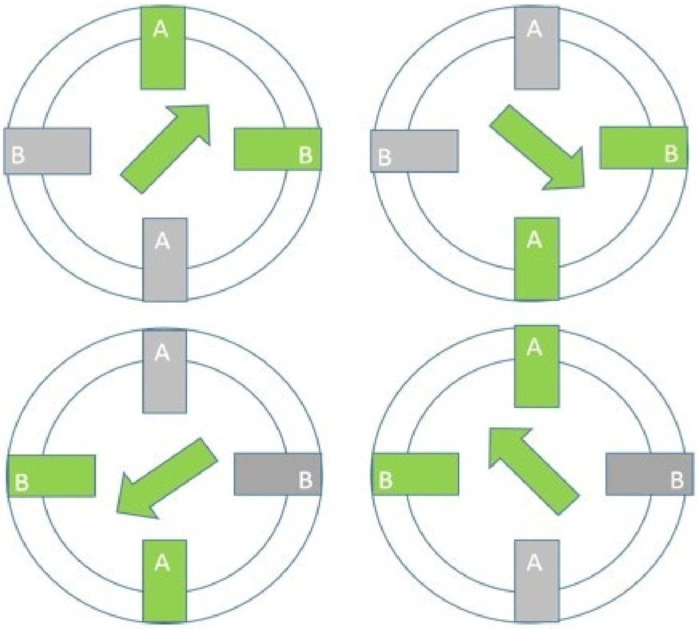

Figure 2.10: Two phase on, Full step

Half step excitation mode is a combination of one phase on and two phase on full step modes. This results in half the basic step angle. This smaller step angle provides smoother operation due the increased resolution of the angle. It produces about 15% less torque than two phase on - full step, however modified half stepping eliminates the torque decrease by increasing the current applied to the motor when a single phase is energized.

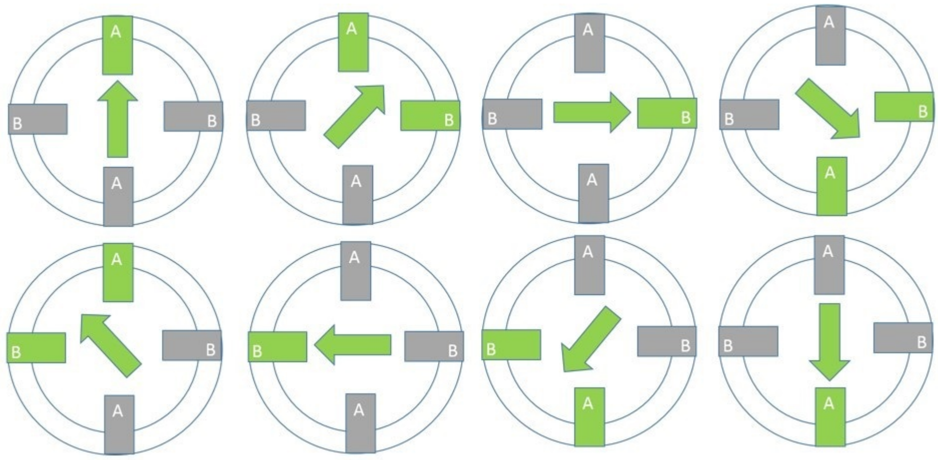

Figure 2.11: One-Two phase on, Half step

Micro-stepping for greater control and smoother operation Micro-stepping can divide a motor's basic step by up to 256 times, making small steps smaller. A Micro drive uses two current sine-waves 90° apart, this is perfect for enabling smooth running of the motor. You will notice that the motor runs is quietly and with no real detectable stepping action. By controlling direction and amplitude of the current flow in each winding, the resolution increases and the characteristics of the motor improve, giving less vibration and smoother operation. Because the sine-waves work together there is a smooth transition from one winding to the other. When current increases in one it decreases in the other resulting in a smooth step progression and maintained torque output

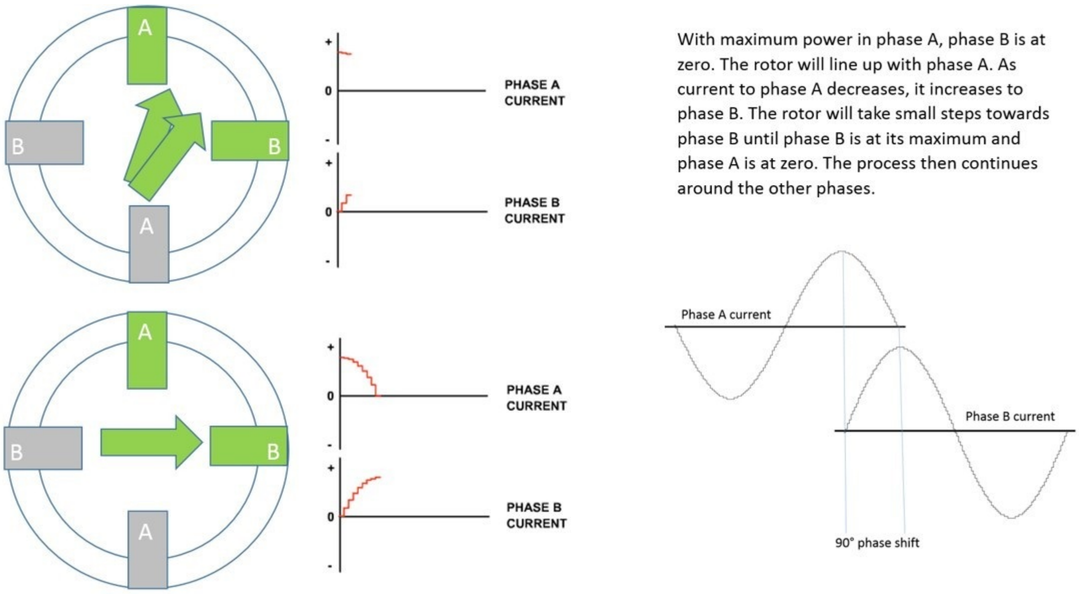

Figure 2.12: Micro-stepping

2.5 Marlin firmware [mrl]

Marlin is an open source firmware for 3D printers. It wan an open source project since August 12, 2011. Marlin is licensed under the GPLv3 and is free for all applications.

One key to Marlin's popularity is that it runs on inexpensive 8-bit Atmel AVR microcontrollers. These chips are at the center of the popular open source Arduino/Genuino platform. The reference platform for Marlin is an Arduino Mega2560 with RAMPS 1.4.

As a community product, Marlin aims to be adaptable to as many boards and configurations as possible also customizatable , extensible, and economical for hobbyists and vendors alike. A Marlin build can be very small, for use on a headless printer with only modest hardware. Features are enabled as-needed to adapt Marlin to added components.

Marlin Firmware runs on the 3D printer's main board, managing all the real-time activities of the machine. It coordinates the heaters, steppers, sensors, lights, LCD display, buttons, and everything else involved in the 3D printing process.

2.5.1 Configuration

This firmware is designed so that it can easily and freely be modified as needed, edits such as, Type of electronics, Printer geometry, Type of temperature sensor, Endstop configuration and LCD controller.

More editing to the Configuration.h file also includes:

- **Steps Per Unit**
- **Maximum Feed Rate (mm/s)**
- **Maximum Acceleration (mm/s²)**

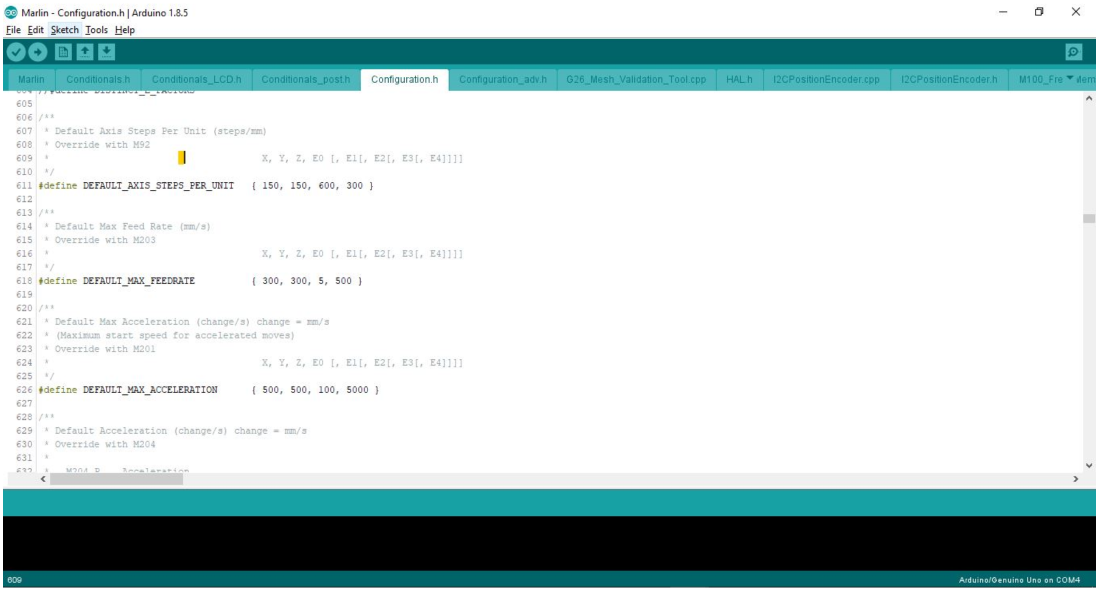

Figure 2.13: Steps Per Unit, Maximum Feed Rate and Maximum Acceleration

- **Driver type**

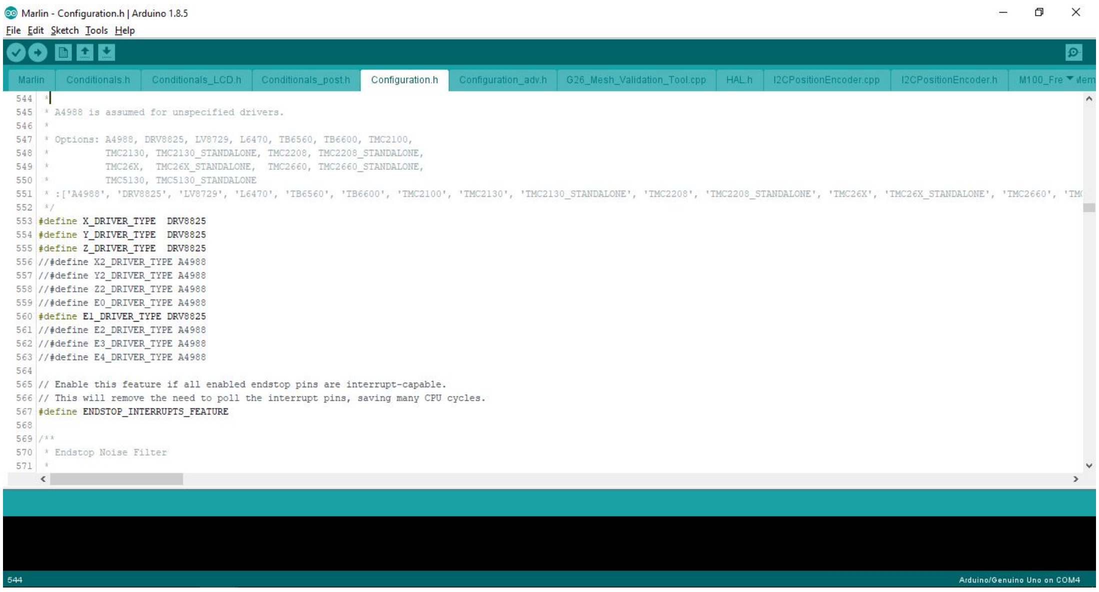

Figure 2.14: Driver type

- **Printing base size**

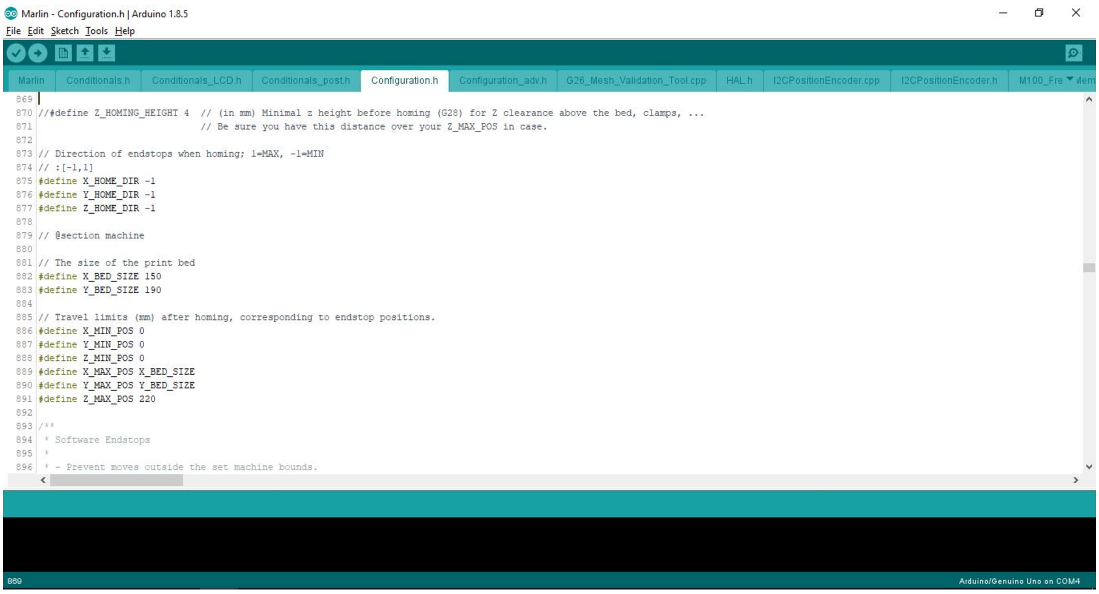

Figure 2.15: Printing base size

- **Default Nominal Filament Diameter**

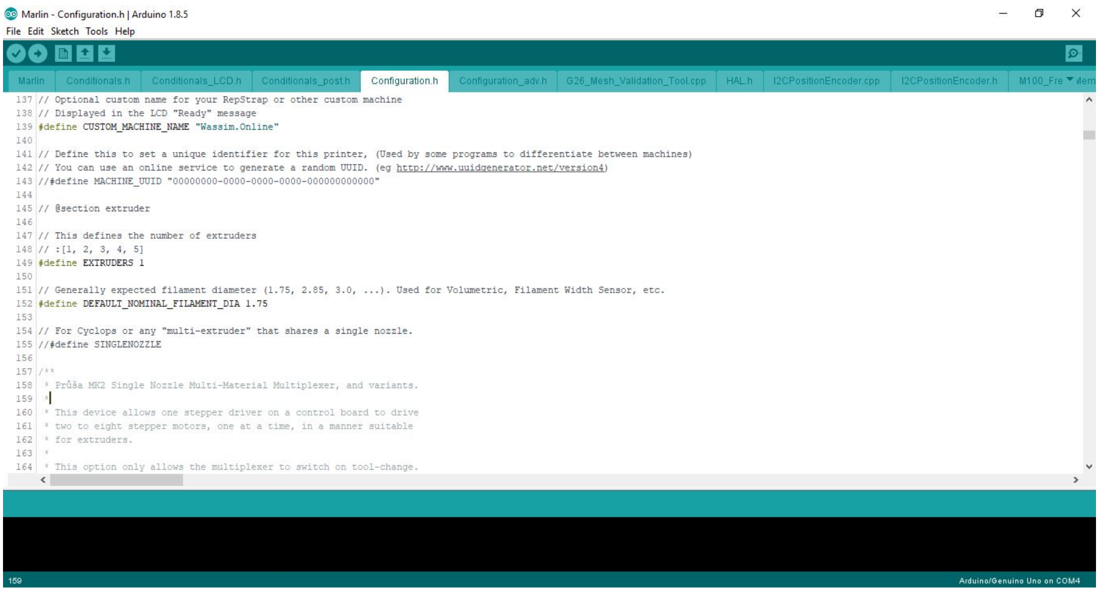

Figure 2.16: Default Nominal Filament Diameter

Conclusion

In this chapter we've seen different types of fused filament fabrication 3D Printers, and we have chosen to build a 3D Printer using theH-bot mechanism, we've also seen the main components of the machine that we will make and some details about how they work,during the following chapter, we will see some common computer aided design software and make our concept using one of them.

Chapter 3

Concept of the 3D printer

Introduction

In this chapter we will make a 3D sketch as a concept to the 3D printer that we will build, this design's purpose is to give us a general idea on how the end result may look like

3.1 Components of FFF 3D printer

After looking at different examples of 3D printers, the components of our printer are now set. It will consist of four stepper motors,one for extruding the filament, one for the movement along the Z axis and two of them for X and Y movements, a printing head to melt the filament at the desired temperature with a cooling fan, an ARDUINO mega board to send control signals to the stepper motors and heater as required.

The ARDUINO mega board will be equipped with a RAMPS board which facilitates interfacing the ARDUINO mega, as it fits the entire electronics needed for the 3D printer that we will make, which include stepper drivers and limit switches, generaly known as end-stops, an LCD display to see different useful information like current temperature and the percentage of printing progress, etc.

In what follows a list of each component and their detailed description:

3.1.0.1 Stepper motor

The stepper motor is a brush less motor that rotates by tiny angles called steps according to the electrical pulses received in its coils,stepper motors are used for precise angular positioning, its biggest advantage compared to other motors is the precise positioning and speed control also it facilitates the synchronization of movement of several motors.

Types of Stepper motor [stpb] There are three main types of stepper motors:

- **Permanent magnet stepper**Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets.
- **Variable reluctance stepper**Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.
- **Hybrid synchronous stepper**Hybrid synchronous are a combination of the permanent magnet and variable reluctance types, to maximize power in a small size.

Two-phase stepper motors There are two basic winding arrangements for the electromagnetic coils in a two phase stepper motor: bipolar and unipolar.

- **Unipolar motors** A unipolar stepper motor has one winding with center tap per phase. Each section of winding is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple (e.g., a single transistor) for each winding. Typically, given a phase, the center tap of each winding is made common: giving three leads per phase and six leads for a typical two phase motor. Often, these two phase commons are internally joined, so the motor has only five leads. A microcontroller or stepper motor controller can be used to activate the drive transistors in the right order, and this ease of operation makes unipolar motors popular with hobbyists; they are probably the cheapest way to get precise angular movements.

  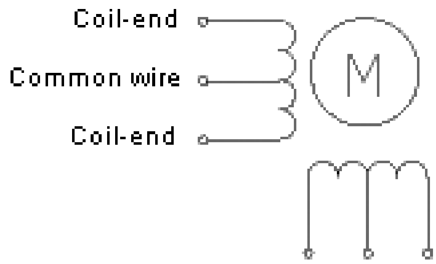

  Figure 3.1: Unipolar stepper motor coils

  For the experimenter, each coil winding can be identified by touching the terminal wires together in PM motors. If the terminals of a coil are connected, the shaft becomes harder to turn. One way to distinguish the center tap (common wire) from a coil-end wire is by measuring the resistance. Resistance between common wire and coil-end wire is always half of the resistance between coil-end wires. This is because there is twice the length of coil between the ends and only half from center (common wire) to the end. A quick way to determine if the stepper motor is working is to short circuit every two pairs and try turning the shaft. Whenever a higher than normal resistance is felt, it indicates that the circuit to the particular winding is closed and that the phase is working.

- **Bipolar motors** Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (however there are several off-the-shelf driver chips available to make this a simple affair). There are two leads per phase, none are common.

3.1.0.2 Characteristics of the used motors [ste]

In this project we will be using stepper motors as shown on Figure 3.2 with the following characteristics:

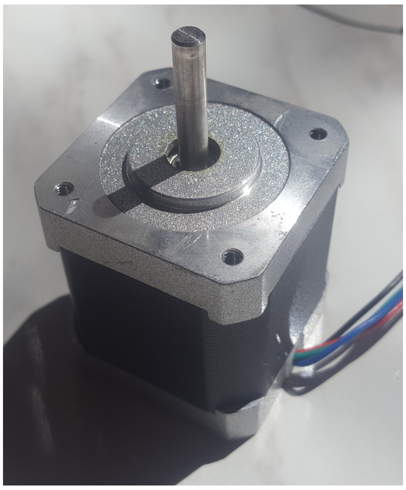

Figure 3.2: NEMA 17 stepper motor

- **Step Angle:** 1.8°
- **Step Angle Accuracy:** ±5%(fullstep,noload)
- **Resistance Accuracy:** ±10%
- **Inductance Accuracy:** ±20%
- **Temperature Rise:** 80°C
- **max Ambient Temperature:** -20°C +50°C
- **Insulation Resistance:** 100 Mega Ohms Min.500VDC
- **Dielectric Strength:** 500VAC for one minute
- **Shaft Radial Play:** 0. 02Max. (450g-load)
- **Shaft Axial Play:** 0.08 Max.(450g-load)
- **Max.radial force:** 28N (20mm from the flange)
- **Max.axial force:** 10N

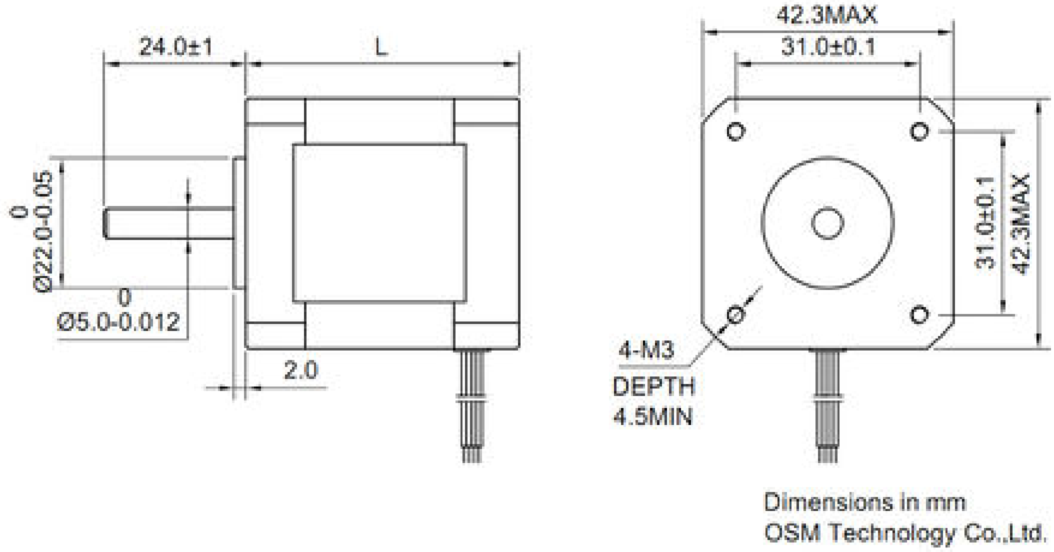

Figure 3.3: Dimensions of NEMA 17 stepper motor[dim]

3.1.1 End-stops

A mechanical endstop or limit-switch is one of the most basic forms of endstops, it is a switch that indicates whether it's active when clicked, or not.

These switches provide protection to the hardware from damage while moving, by making boundaries for the movements. Figure 3.4 shows a mechanical endstop:

Figure 3.4: End-stop

3.1.2 Extruder [ext]

The extruder is responsible for sending the correct amount of filament to the printing head where it's melted and extruded down in thin layers to make a 3d object.

There are two basic types of extruders currently available

- **Bowden extruder:** A bowden extruder is not directly attached to the hot end. Instead, a tube extends from the extruder bodyto the hot end. This is called a bowden tube. The filament is constrained by the tube and travels through it to the printing head.
- **Direct extruder** Direct extruders are simply extruders that are directly attached above the printing head.

Figure 3.5 shows the bowden extruder that we will be using.

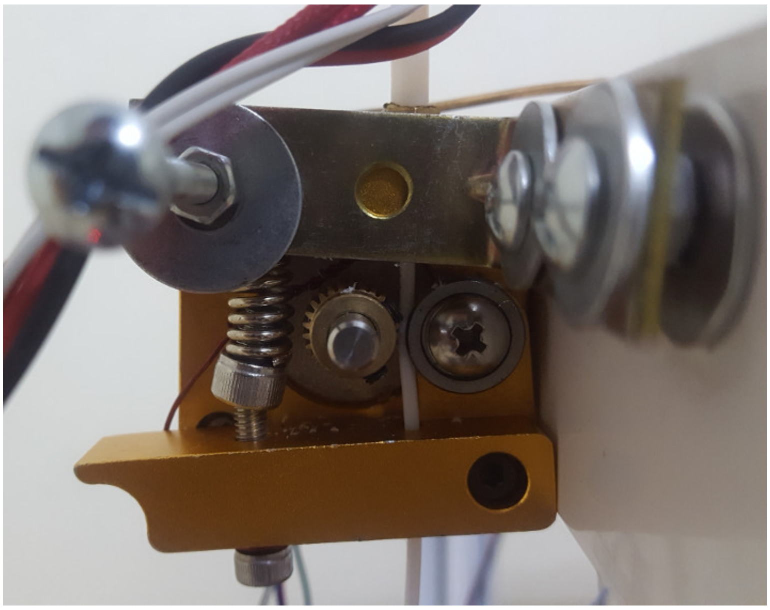

Figure 3.5: Extruder

3.1.3 Printing Head

The printing head also known as hot end, is the part of the 3D printer responsible for melting the filament to be extruded on the printing base, in order to form 3d object layers. Figure 3.6 show a side view of the extruder that we will be using.

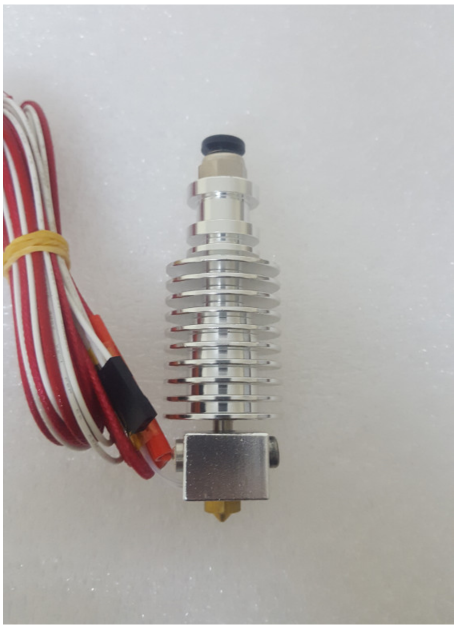

Figure 3.6: Printing head

Figure 3.7 shows a bottom view of the printing head, its important to mention that the nozzle diameter of this printing head is 0.3mm.

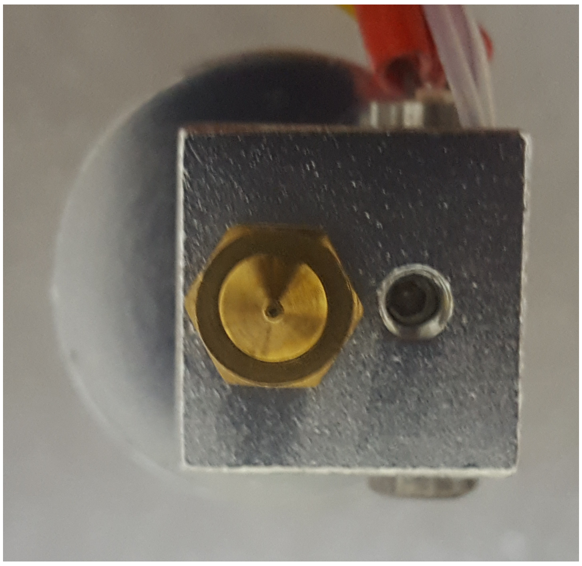

Figure 3.7: Printing head bottom view

3.1.4 3D printer LCD display controller

The LCD display controller shown in Figure 3.8 is a human machine interface which is used to monitor and control the 3D Printer

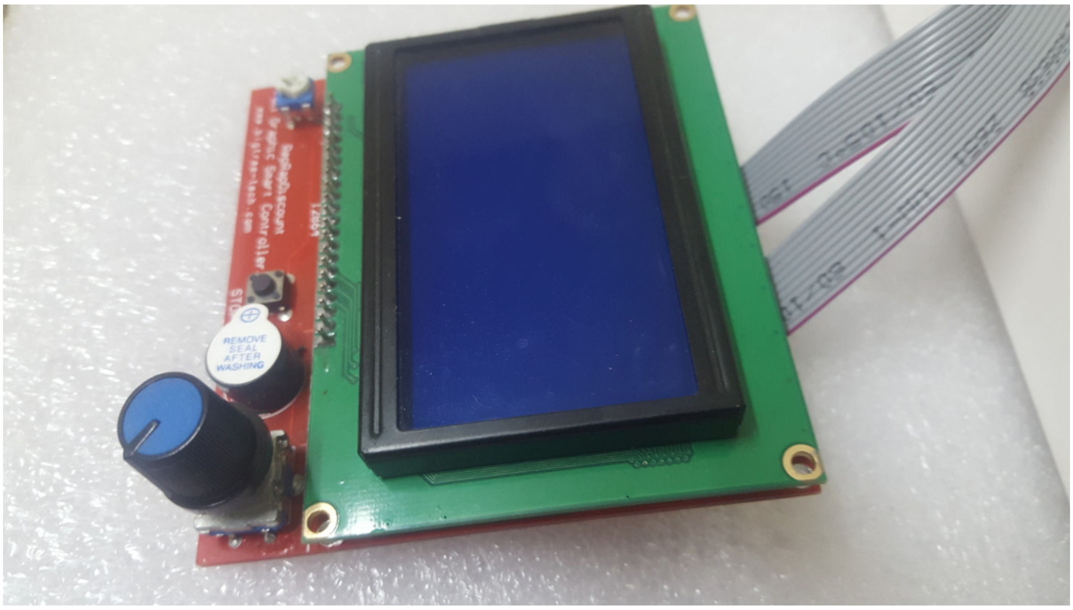

Figure 3.8: 3D Printer LCD display controller

Figure 3.9 shows the LCD display in operation

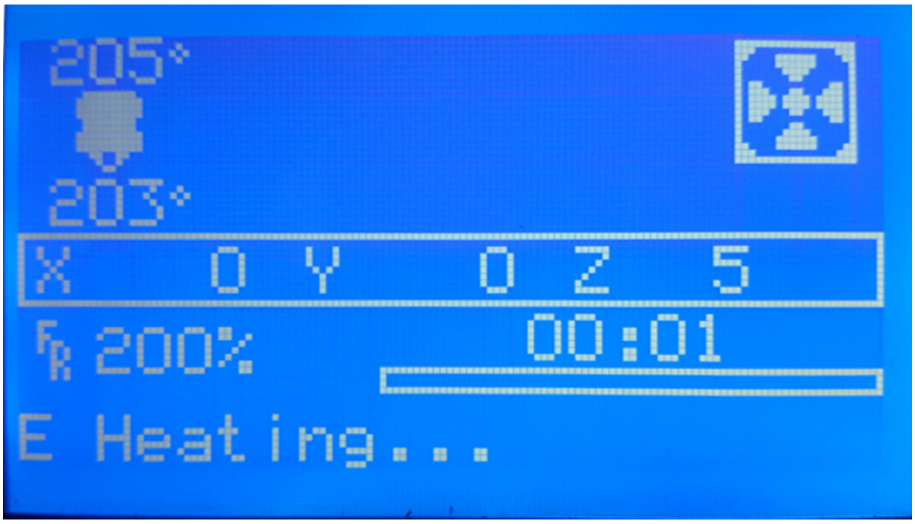

Figure 3.9: 3D printer LCD screen in operation

3.1.5 The ARDUINO mega board

The Arduino Mega 2560 is a micro controller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.[ard]

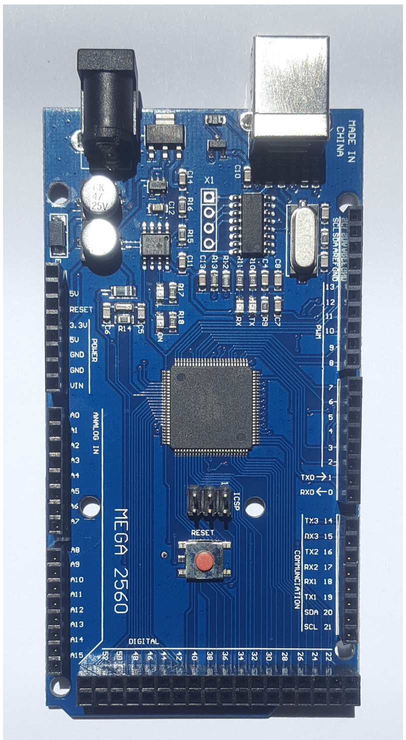

Figure 3.10: Picture of the ARDUINO mega board

3.1.5.1 The Arduino IDE

The Arduino Integrated Development Environment facilitates writing code and uploading it to our Arduino board.

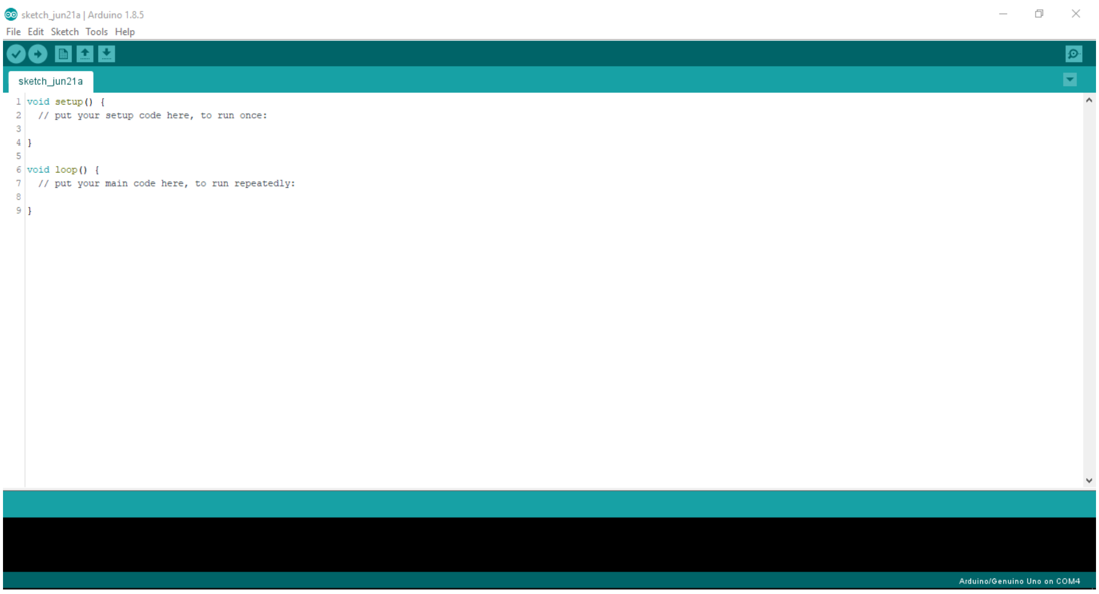

Figure 3.11: Interface of a blank Arduino IDE project

3.1.6 The RAMPS board

RepRap Arduino Mega Pololu Shield, or RAMPS for short. It is designed to fit the entire electronics needed for a RepRap in one small package for low cost. RAMPS interfaces mix Arduino Mega with the powerful Arduino MEGA platform Ramps1.4Plus and has plenty room for expansion. The modular design includes plug in stepper drivers and extruder control electronics on an Arduino MEGA shield for easy service, part replacement, upgrade-ability and expansion. Additionally, a number of Arduino integrade boards can be added to the system as long as the main RAMPS board is kept to the top of the stack. [ram]

Figure 3.12 shows a picture of The RAMPS board that we will use

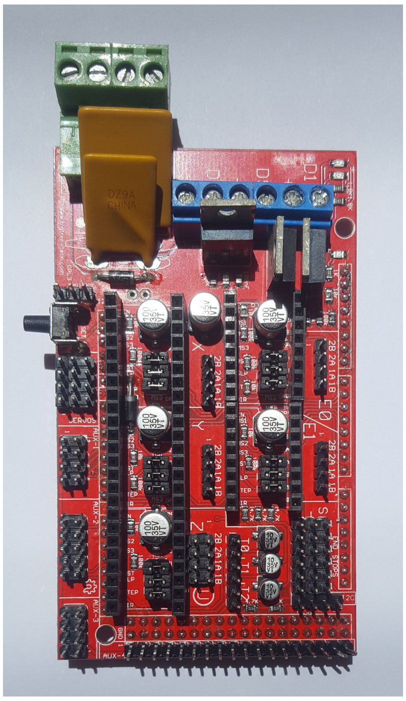

Figure 3.12: Picture of The RAMPS board

3.1.7 Stepper Motor Driver (DRV8825)

Stepper motor drivers are specifically designed to drive stepper motors, which are capable of continuous rotation with precise position control, even without a feedback system. Our stepper motor drivers offer adjustable current control and multiple step resolutions, and they feature built-in translators that allow a stepper motor to be controlled with simple step and direction inputs. These modules are generally basic carrier boards for a variety of stepper motor driver integrated circuits that offer low-level interfaces like inputs for directly initiating each step. An external microcontroller is typically required for generating these low-level signals. [stpa]

Figure 3.13 is an image of the type of the stepper driver that we will be using in our project

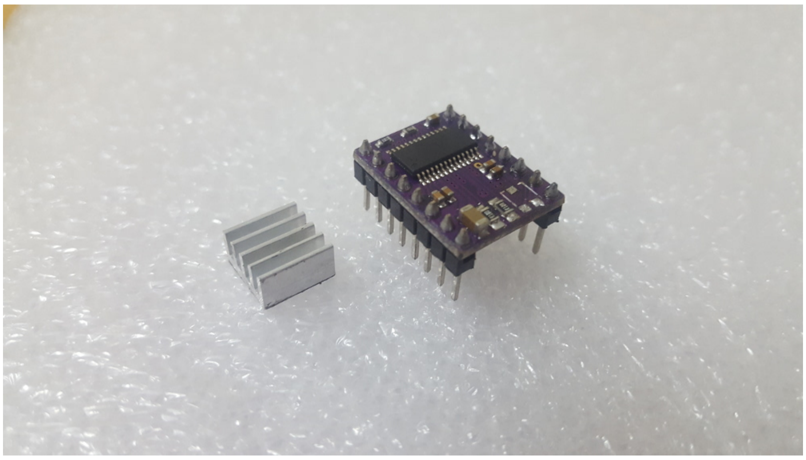

Figure 3.13: stepper driver drv8825 with heat-sink

Figure 3.14 shows a simplified schematics of the used stepper driver

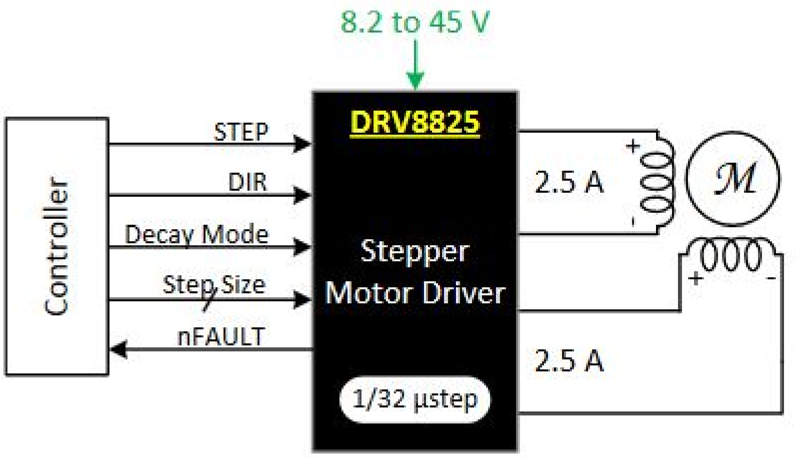

Figure 3.14: Stepper driver simplified schematics [TI11]

A simple STEP/DIR interface allows easy interfacing to controller circuits. Mode pins allow for configuration of the motor in full-step up to 1/32-step modes. Decay mode is configurable so that slow decay,fast decay or mixed decay can be used. A low-power sleep mode is provided which shuts down internal circuitry to achieve very low quiescent current draw. This sleep mode can be set using a dedicated nSLEEP pin.[TI11]

Figure 3.15 shows the stepper driver functional block diagram:

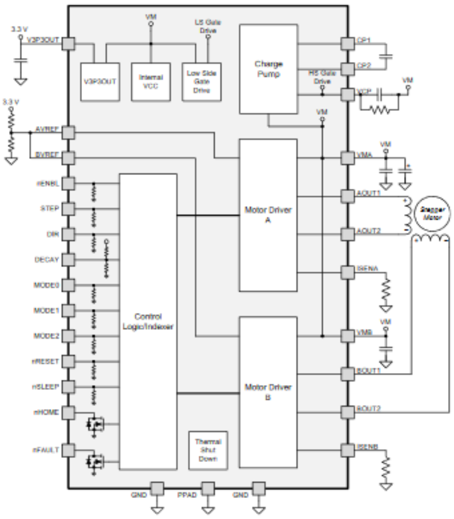

Figure 3.15: functional block diagram of the stepper driver [TI11]

[TI11]

Figure 3.16 shows the stepper driver back view:

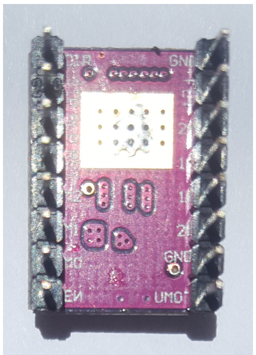

Figure 3.16: stepper driver back view

Figure 3.17 shows micro-stepping current waveform of the used stepper driver

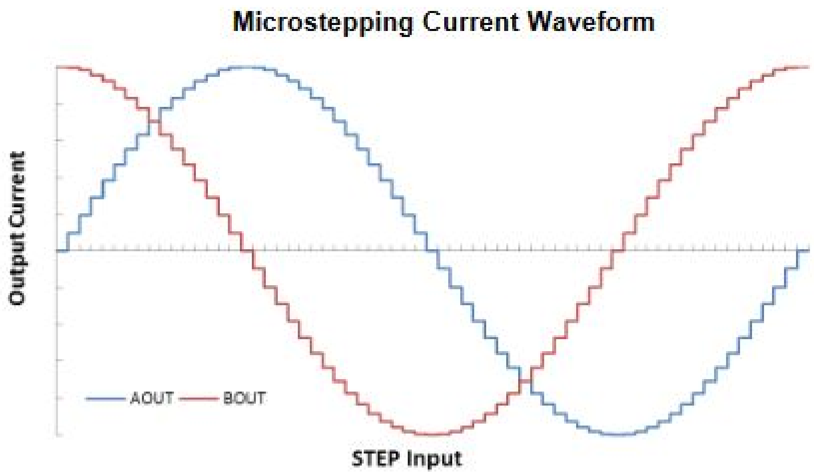

Figure 3.17: Stepper driver micro-stepping current waveform [TI11]

3.2 Common CAD software

Making a 3D design to visualize a concept or to model a 3D object for printing requires a computer aided design software (CAD), following is a list of different CAD software that serve our purpose:

- **Solid Works** Solid works CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. [sld16]

  Figure 3.18 shows the logo of the CAD software Solid Works.

Figure 3.18: Solid Works logo [sw]

Figure 3.19 shows the user interface of the CAD software Solid Works.

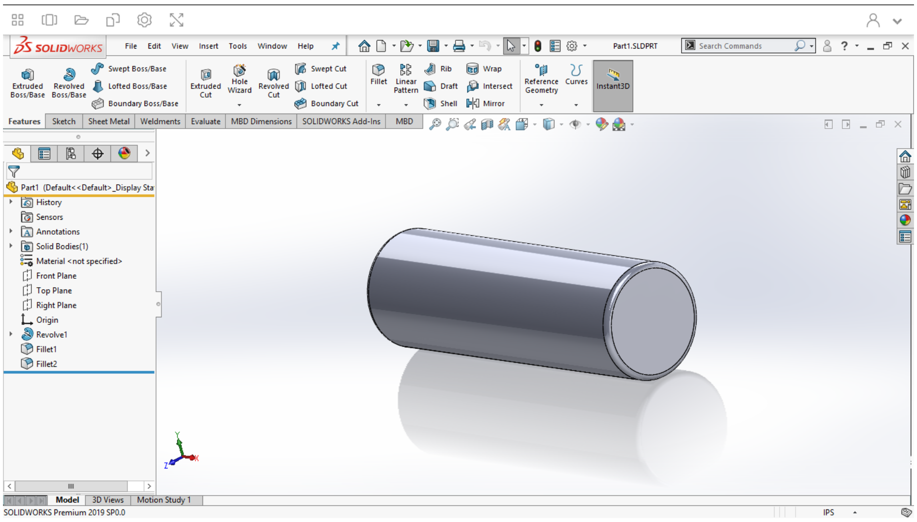

Figure 3.19: User interface of the CAD software Solid Works

- **FreeCAD**

  a 3D parametric modeler originally created to design real-life objects of any size. Parametric modeling allows us to easily modify the designs made by returning to the history of the model and changing its parameters. [fre]

  Figure 3.20 shows the logo of the CAD software FreeCAD.

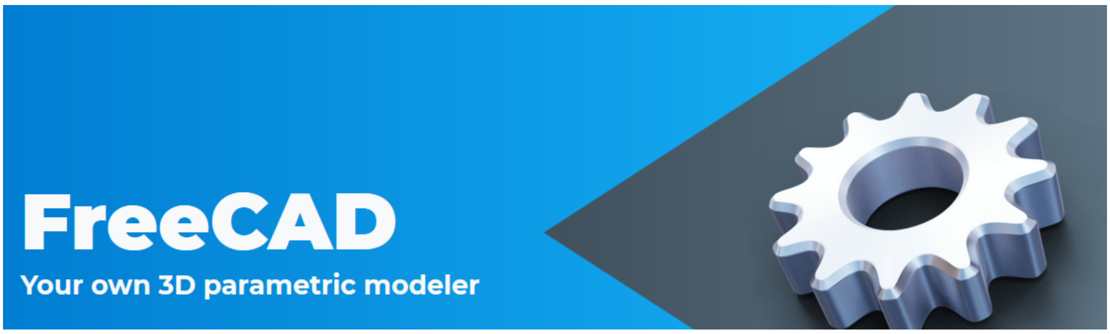

Figure 3.20: FreeCAD [fre]

Figure 3.21 shows the user interface of the CAD FreeCAD.

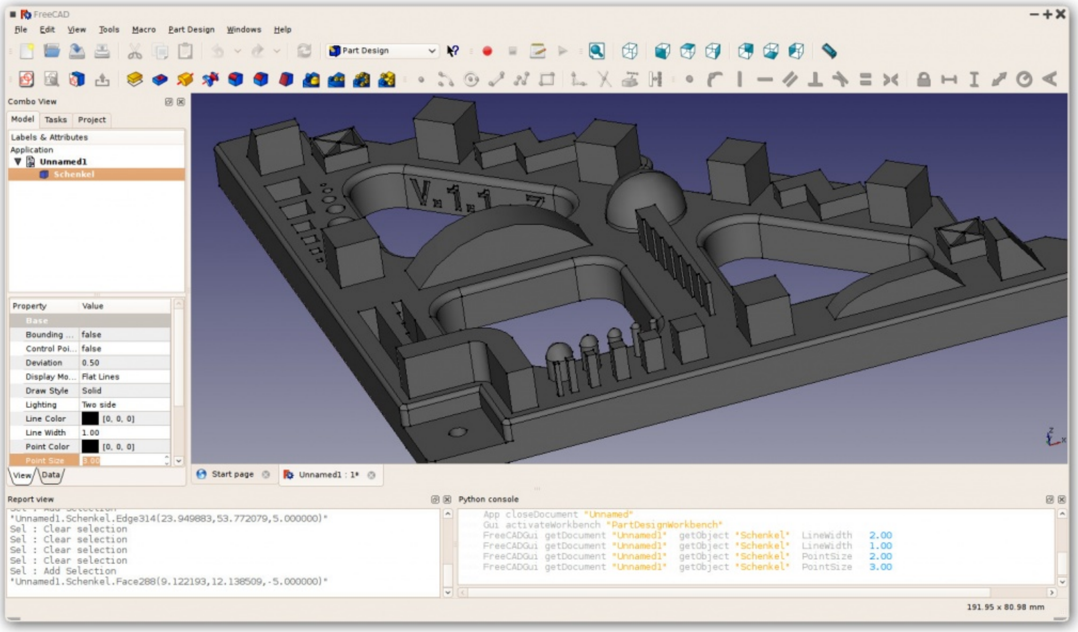

Figure 3.21: User interface of the CAD software FreeCAD[fre]

- **DesignSpark Mechanical** DesignSpark Mechanical allows engineers to quickly design and change product concepts in 3D without having to learn complex traditional CAD software. Results include faster turnaround times, zero investment on procuring/training with new CAD software[dsm]

  Figure 3.22 shows the splash screen of the software,Figure 3.23 shows it's user interface.

Figure 3.22: Design spark mechanical splash screen

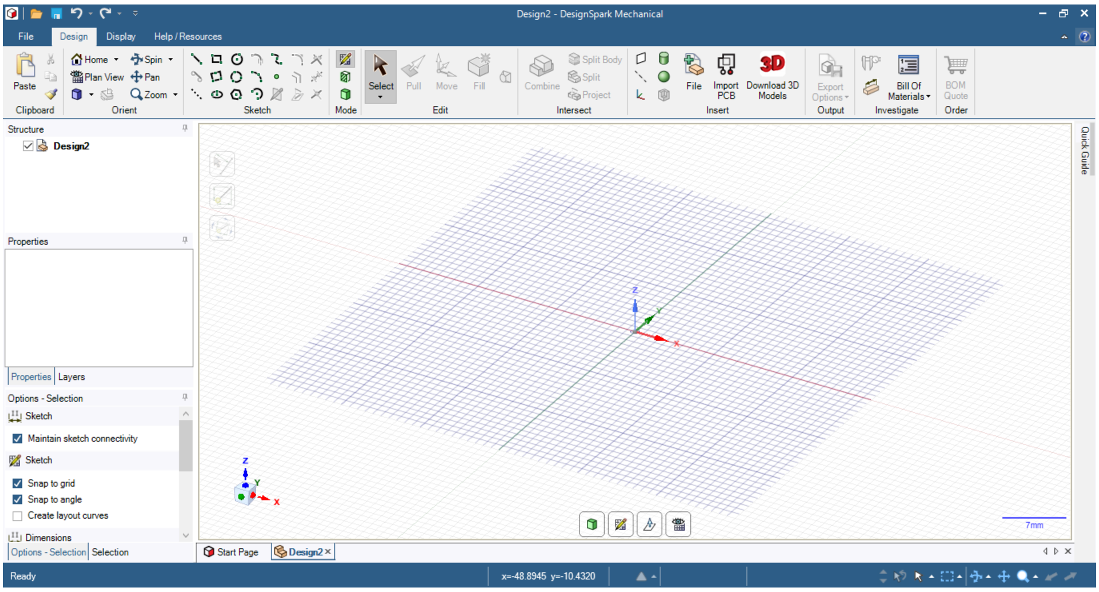

Figure 3.23: Design spark mechanical user interface

- **Blender 3D**Blender is the free and open source 3D creation suite. It supports the entirety of 3D modeling, animation, simulation, rendering, compositing and motion tracking. Advanced users employ Blender's API for Python scripting to customize the application and write specialized tools; often these are included in Blender's future releases. Blender is well suited to individuals and small studios who benefit from responsive development process. [bln]

  Figure 3.24 shows the logo of Blender.

Figure 3.24: Blender logo [bln]

The user interface of Blender is as shown on the next two figures, Figure 3.25 shows the rendered view of our 3D printer's mechanism concept,and Figure 3.26 shows the wire-frame view.

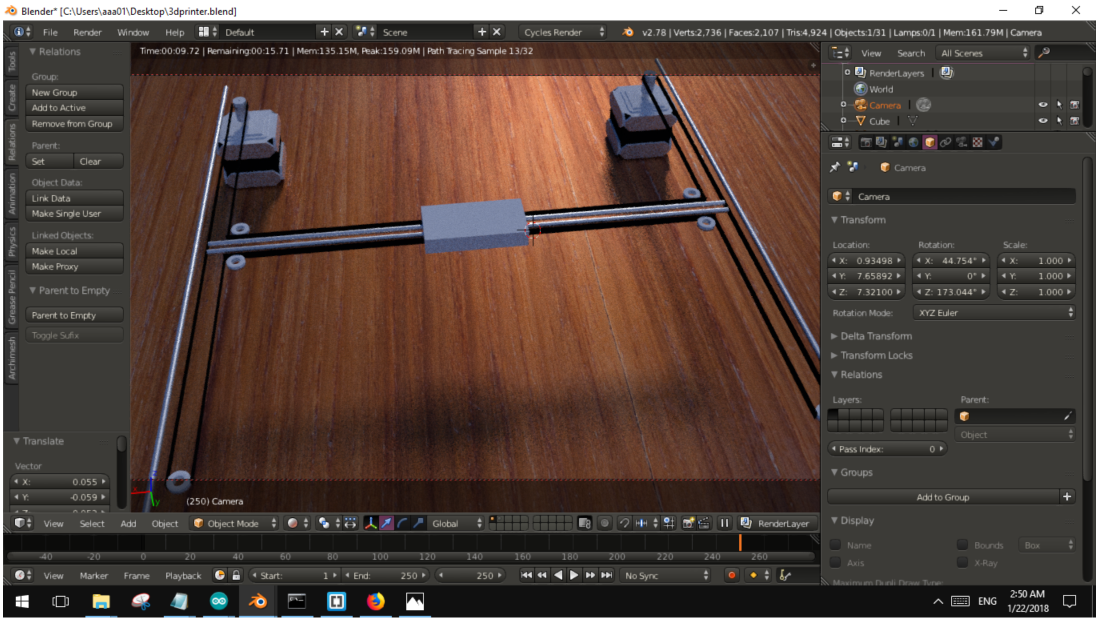

Figure 3.25: User interface of Blender

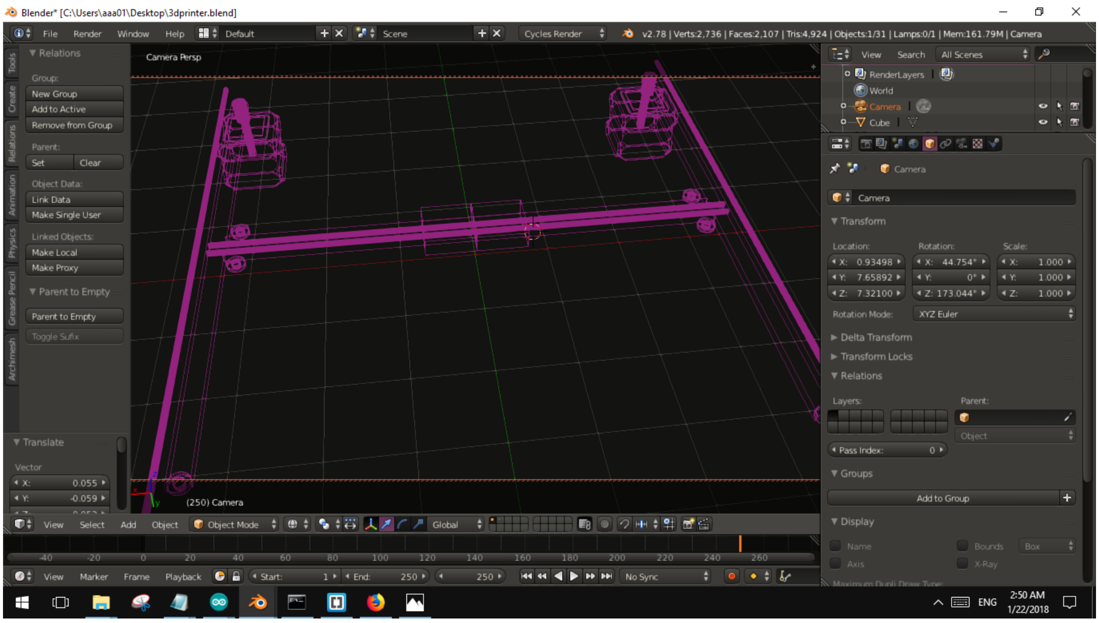

Figure 3.26: User interface of Blender[fre]

- **Autodesk Fusion 360 [fu3]**

  Autodesk Fusion 360 is an integrated CAD, CAM, and CAE software, that simplifies the entire workflow of 3D Design and Modeling, Simulation, Generative Design and Manufacturing with one unified platform.

  Figure 3.27 shows the logo of the CAD software Fusion 360.

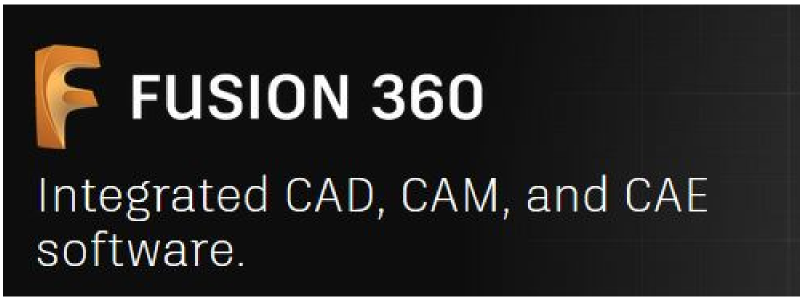

Figure 3.27: Fusion 360 [fre]

Figure 3.28 shows the user interface of Fusion 360.

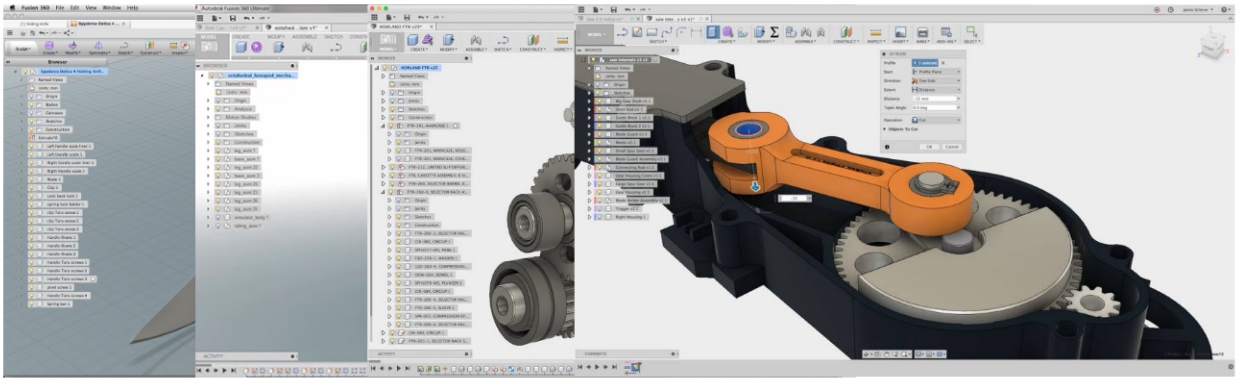

Figure 3.28: User interface of Fusion 360[fre]

3.2.1 Choosing a CAD software

There are many CAD programs for this purpose but we will be using a piece of free software called "DesignSpark Mechanical", the main reasons why we choose this program is because it's cost free and very easy to use compared to the other programs listed above, Figure 3.29 shows the splash screen of the software that we will be using,Figure 3.30 shows it's user interface in a blank project.

Figure 3.29: Design spark mechanical splash screen

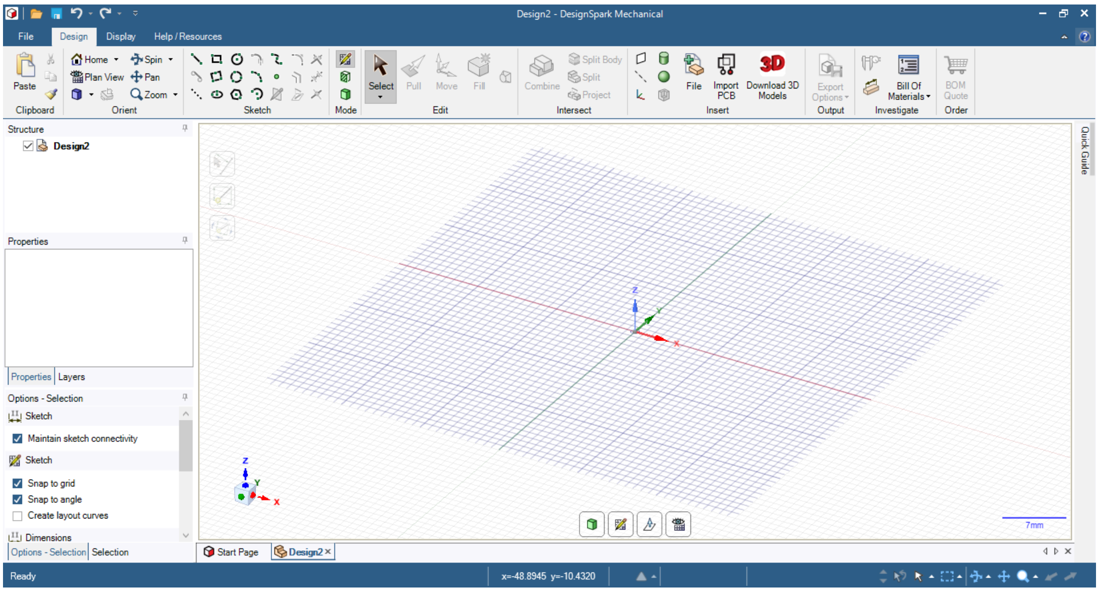

Figure 3.30: Design spark mechanical user interface

3.3 Designing main parts

3.3.0.1 Stepper motor

Figure 3.31 shows the 3D design of a stepper motor

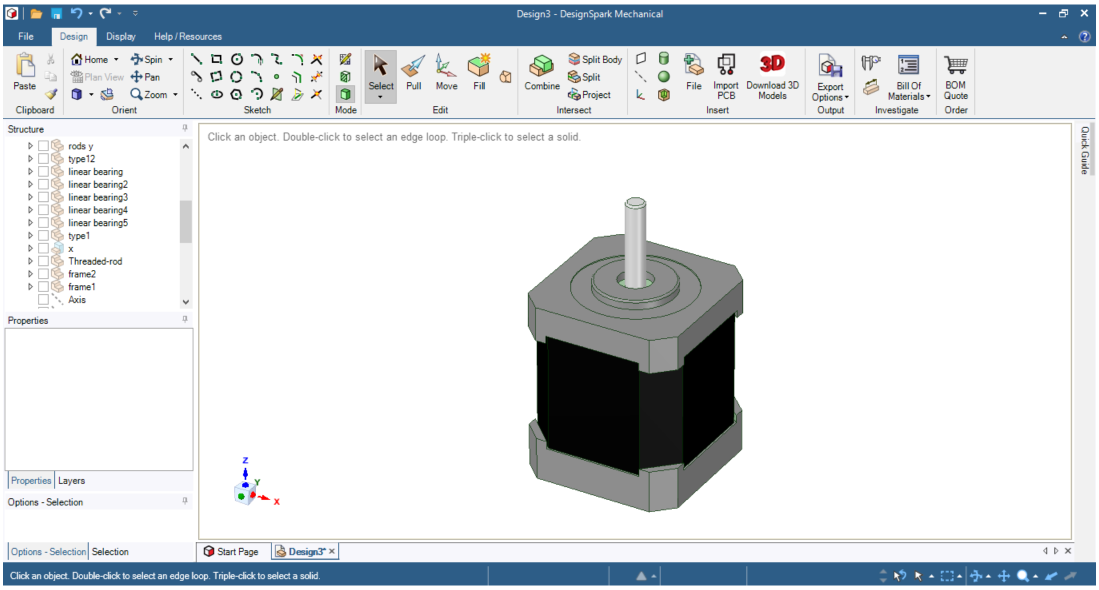

Figure 3.31: 3D design of a stepper motor

3.3.0.2 Hot-end

Figure 3.32 shows the 3D design of the hot-end :

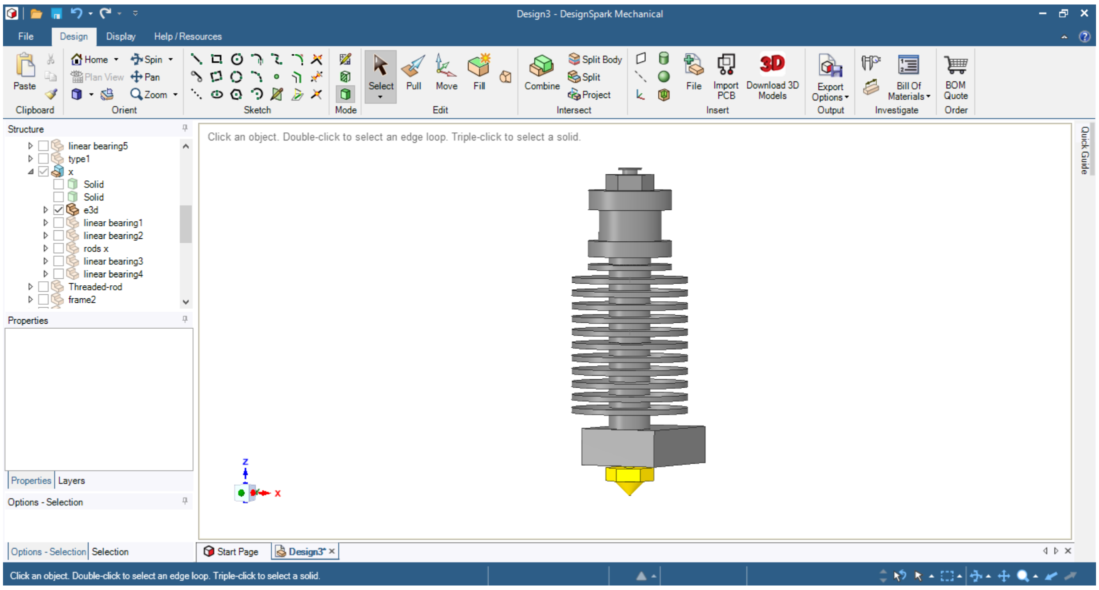

Figure 3.32: 3D design of the hot-end

3.3.0.3 Bearings

Two types of bearings where used , Linear bearings, for the linear X and Y motion and Ball bearings to guide the belt.

- **Linear bearing** Figure 3.33 shows 3D design of a linear bearing.

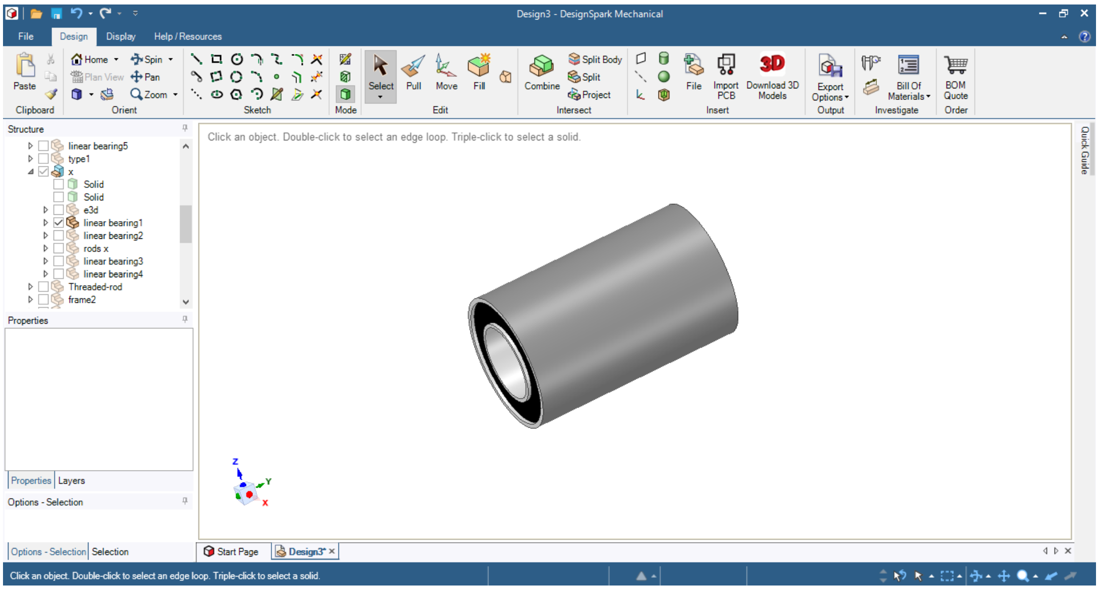

Figure 3.33: 3D design of a linear bearing

- **Ball bearing** Figure 3.34 shows 3D design of a ball bearing.

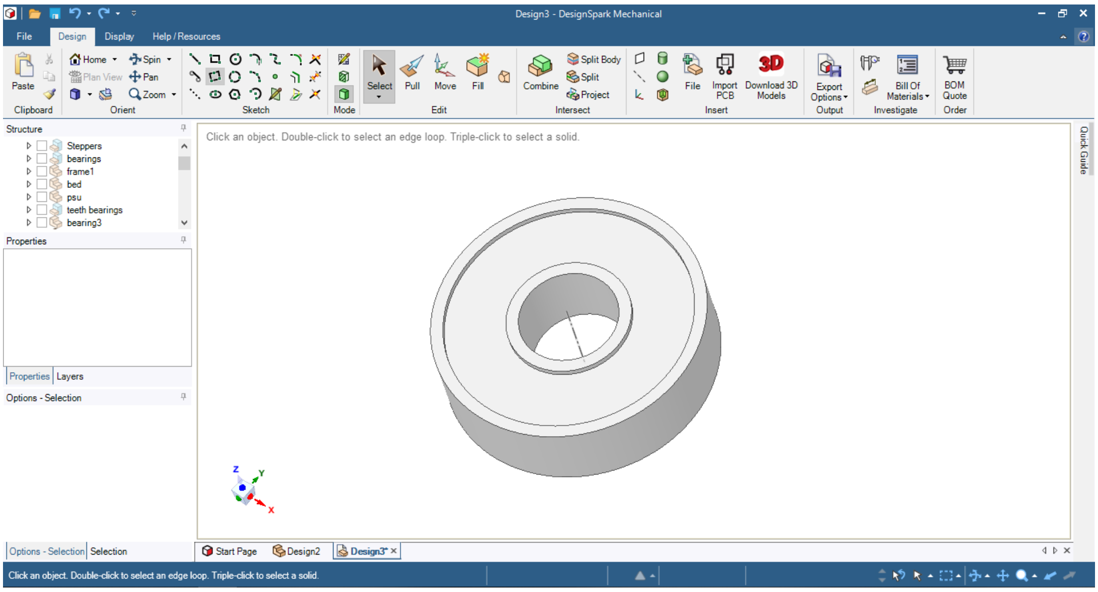

Figure 3.34: 3D design of a ball bearing

3.3.0.4 Timing belt

Figure 3.35 shows 3D design of the timing belt.

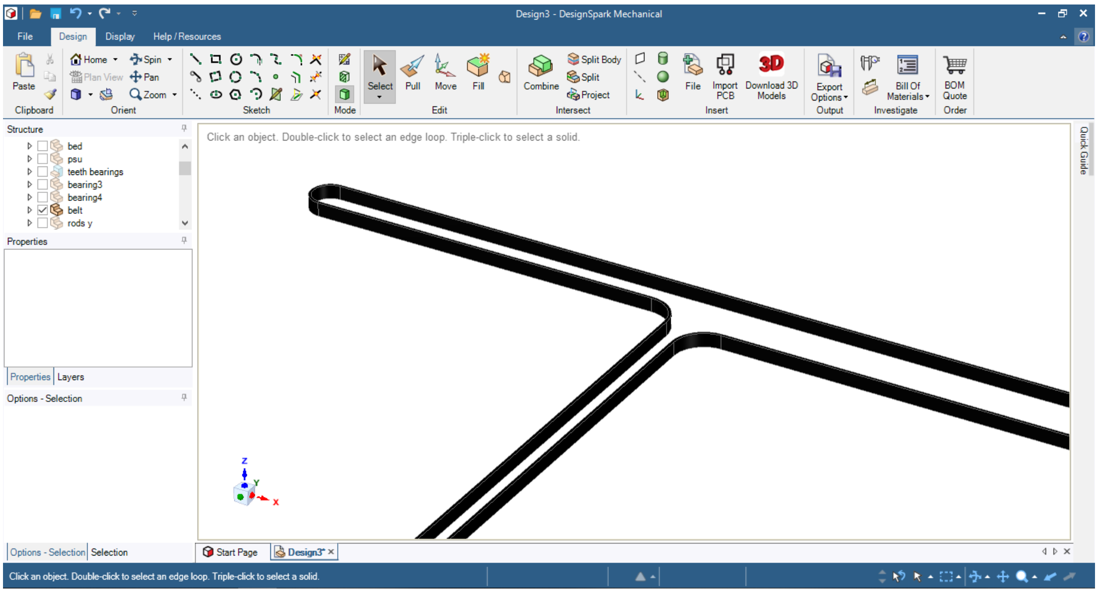

Figure 3.35: 3D design of the of timing belt

3.3.0.5 Timing belt pulley

Figure 3.36 shows 3D design of the timing belt pulley.

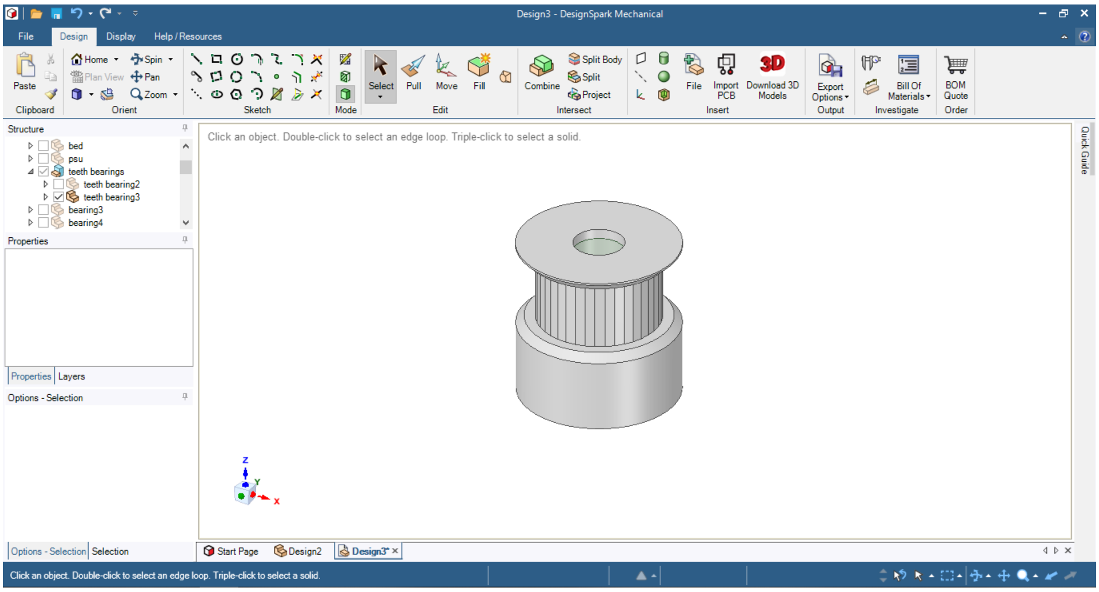

Figure 3.36: 3D design of the of timing belt pulley

3.3.0.6 Threaded rod

Figure 3.37 shows 3D design of the threaded rod.

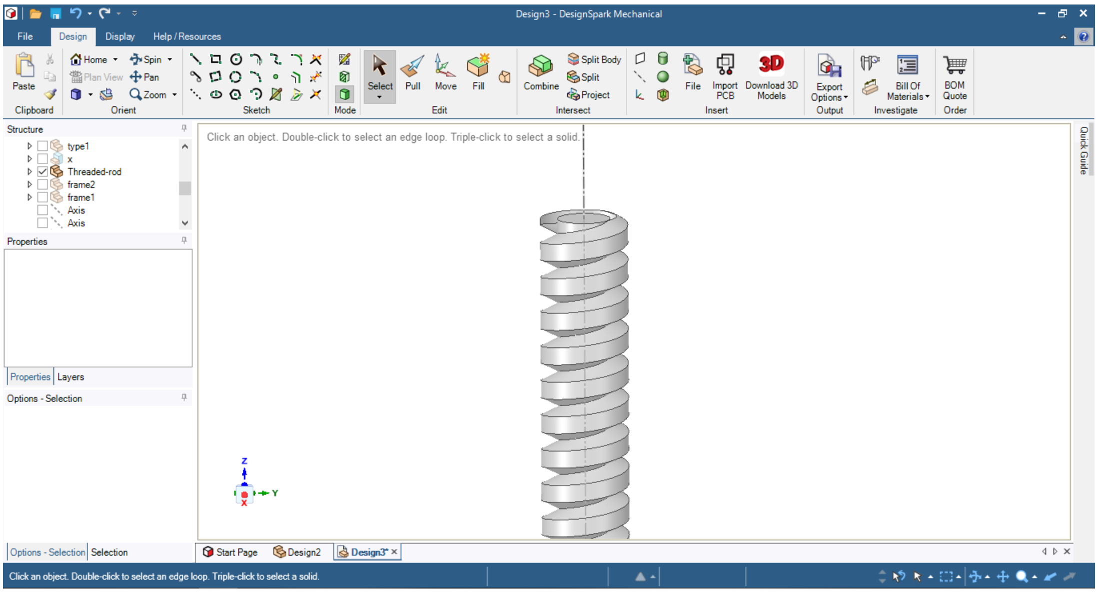

Figure 3.37: 3D design of a threaded rod

3.4 Components assembly

After creating a visual 3D concept of the main mechanical parts that we will be using, now we will start the assembly of those components. Figure 3.38 shows 3D design of the X axis movement components.

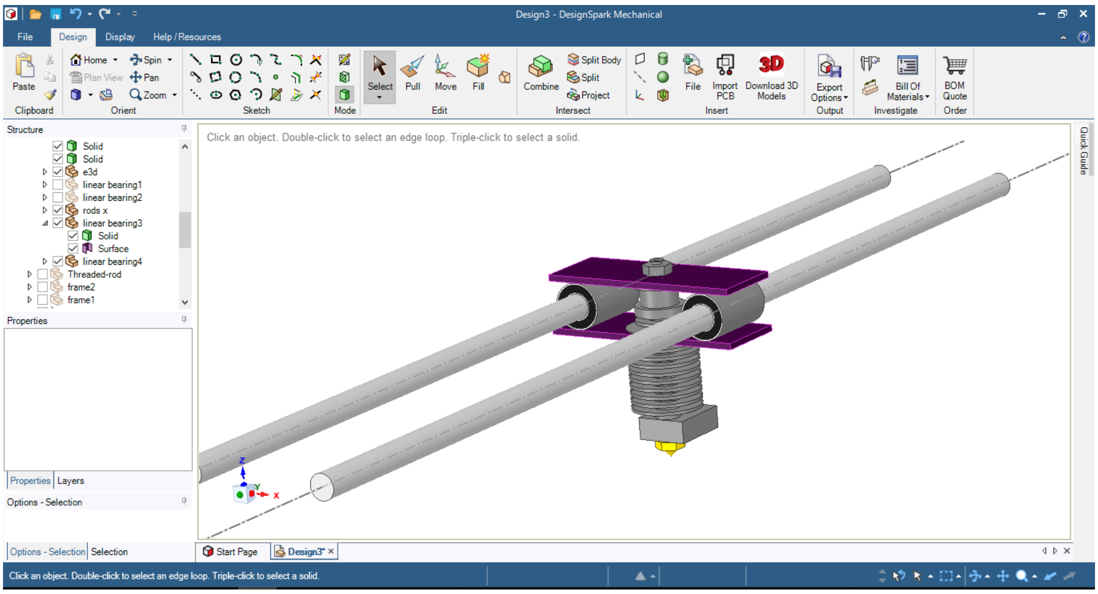

Figure 3.38: 3D design of X axis movement components

Figure 3.39 shows 3D design of X and Y axis movement components.

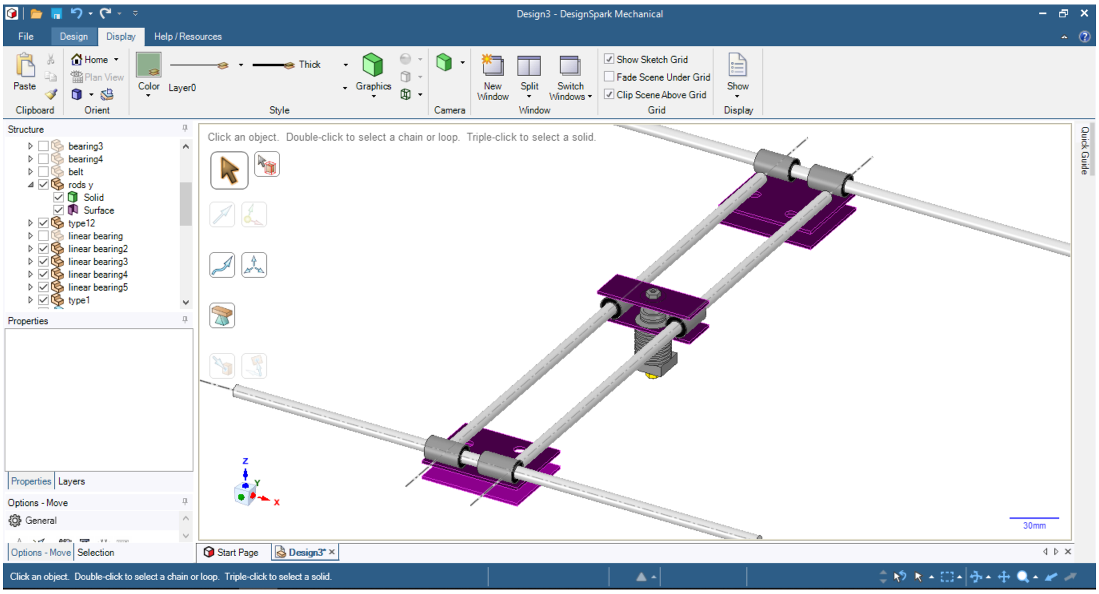

Figure 3.39: 3D design of X and Y axis movement components

Figure 3.40 shows 3D design after mounting bearings and belt.

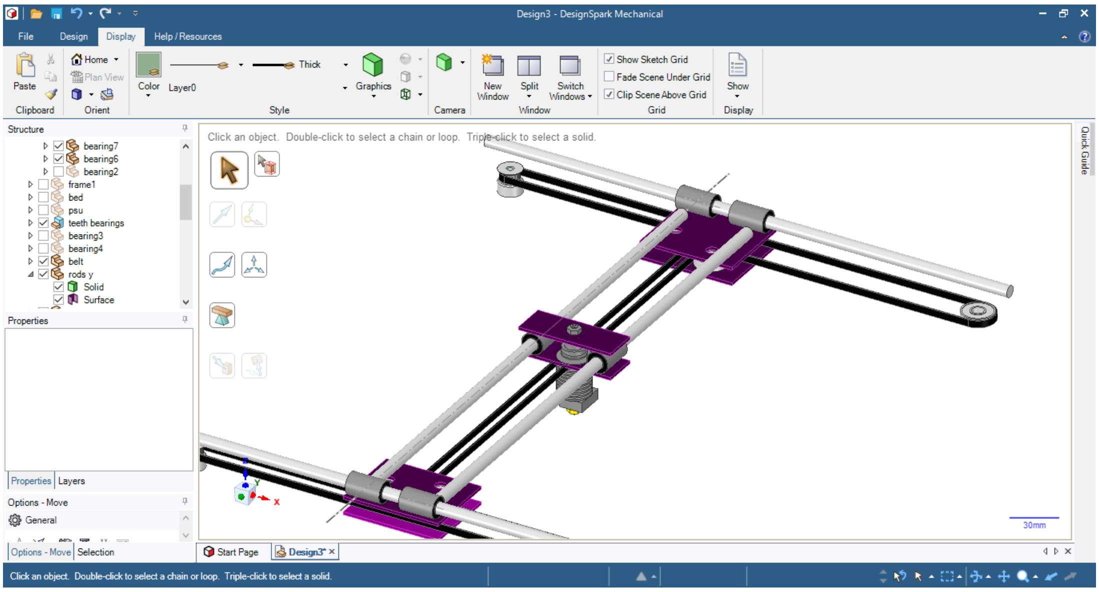

Figure 3.40: Bearings and belt installation

Figure 3.41 shows the top view of the 3D printer mechanism.

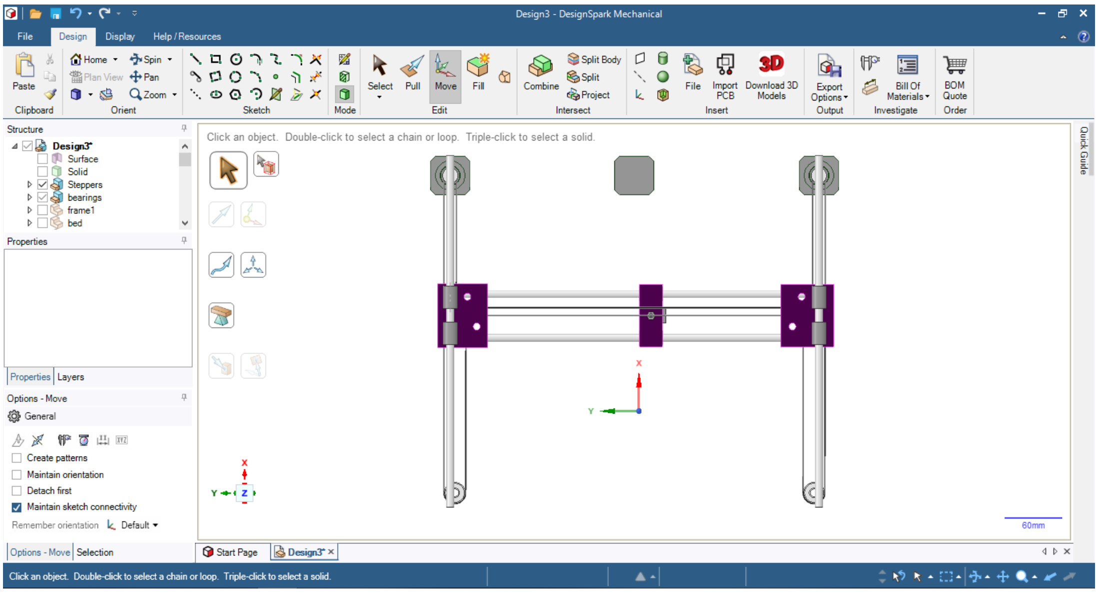

Figure 3.41: Top view of the 3D printer mechanism

Figure 3.42 shows the initial concept of the 3D printer mechanism parts without frame, in addition to the printing base.

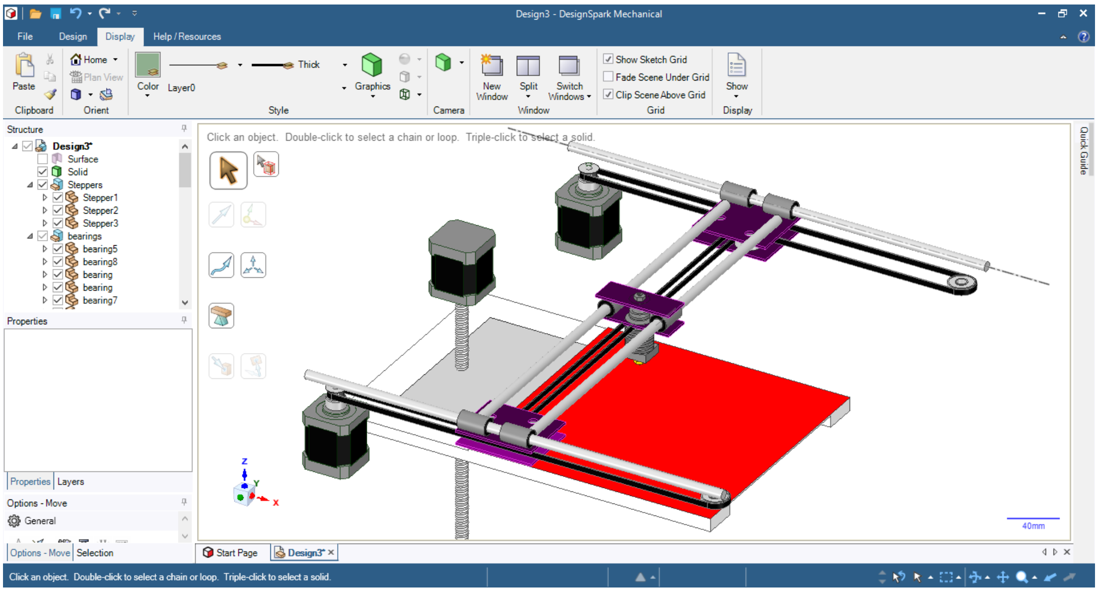

Figure 3.42: Initial concept of the 3D printer without frame

Figure 3.43 shows the initial concept of the 3D printer mechanism parts mounted on a suggested frame in order to have a basic idea of how the end result may look like.

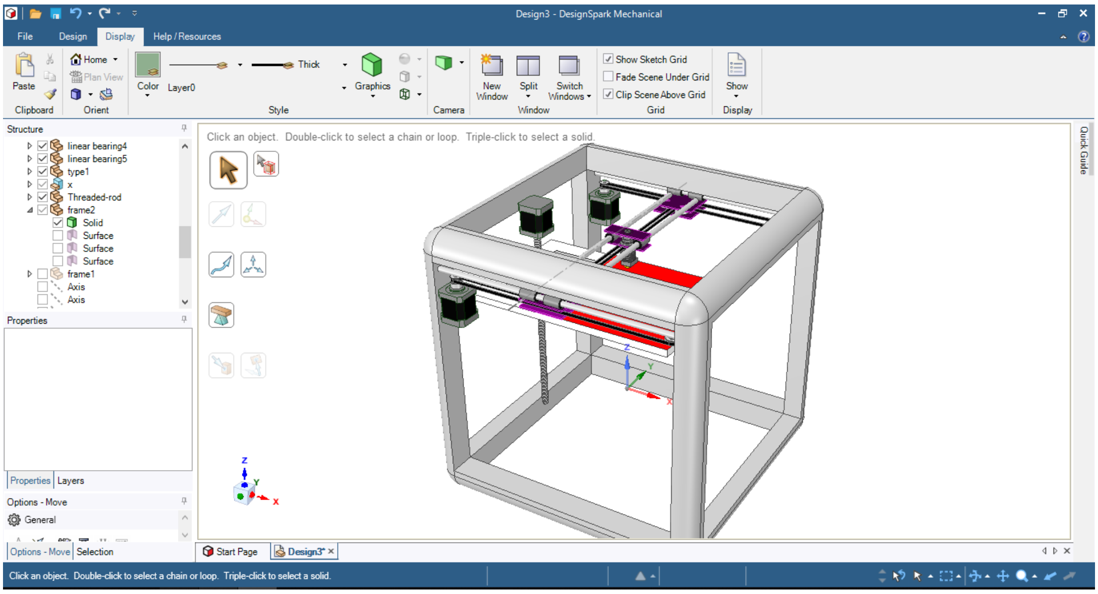

Figure 3.43: initial concept of the 3D printer

Conclusion

After choosing a 3d design software and creating a concept for our machine we now have a basic idea of the end result that we are willing to achieve, next, we will use available tools and components to make this concept a reality.

Chapter 4

Realization of the 3D printer

Introduction

During this chapter we will be turning the concept of the 3D Printer which we designed earlier into reality, the first build we will be using wood as a frame, after that we will disassemble the wooden frame of printer and rebuild is using aluminum, we will also demonstrate the process of creating a 3d model and actually 3D printing it.

4.1 First build and test

4.1.1 Mounting parts of the machine

Figure 4.1 shows the X and Y axis movement components of the printer, first we will run a 2d print test on a paper using a dry inc pen, after that we will mount the base and assemble the rest of the machine Figure 4.2 shows first 2d printing test.

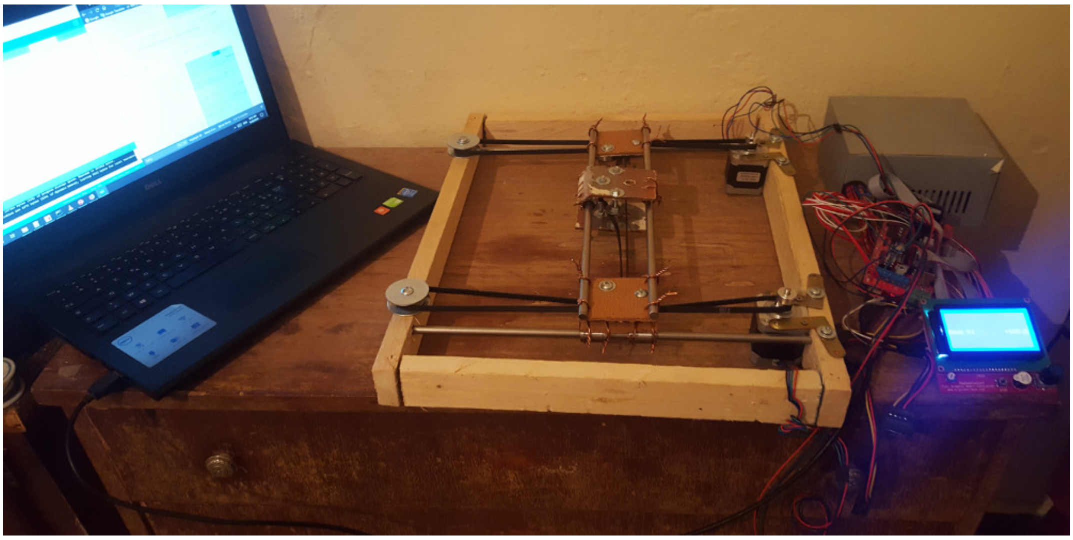

Figure 4.1: 2d printer

After running this first 2d printing test, we notice that it has decent precision, so now we will start assembling the rest of the printer components.

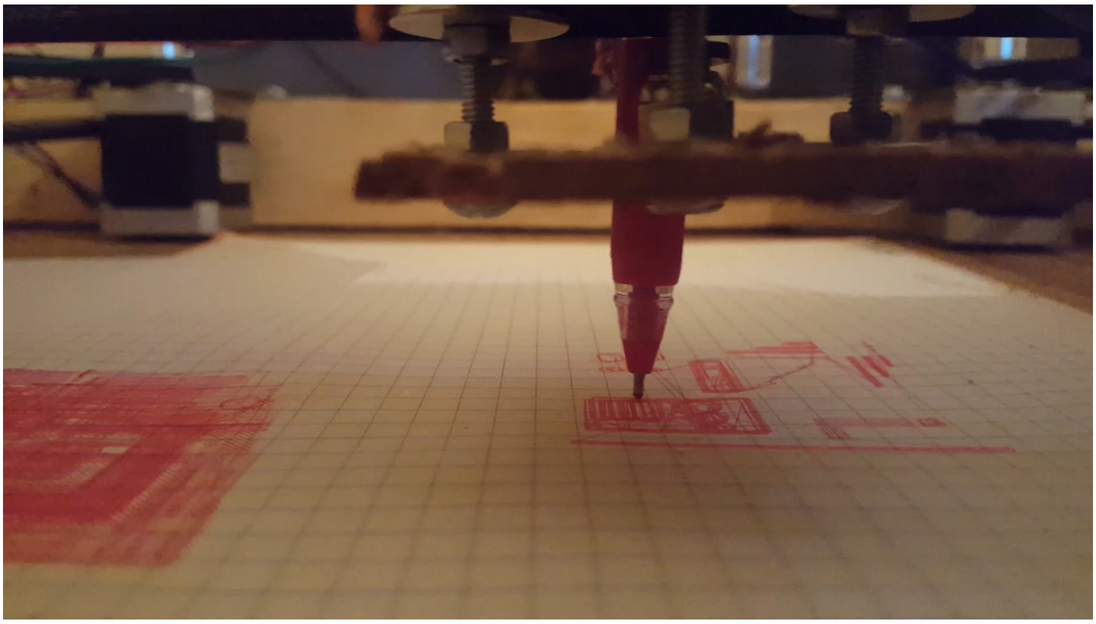

Figure 4.2: First 2d printing test

Figure 4.3 shows a view from inside the machine after mounting the base and the threaded rod which allows movement of the base on the Z axis.

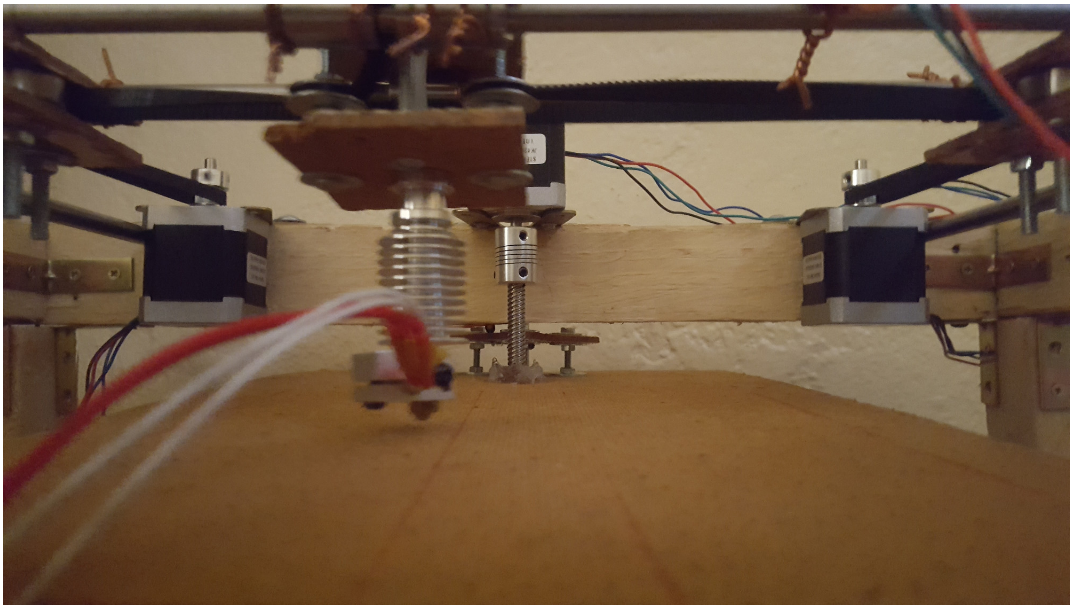

Figure 4.3: After mounting the base and the z axis

The printer head and extruder as shown on Figure 4.4 where also installed and connected to the board, now all is left is trying to making our first 3D Print.

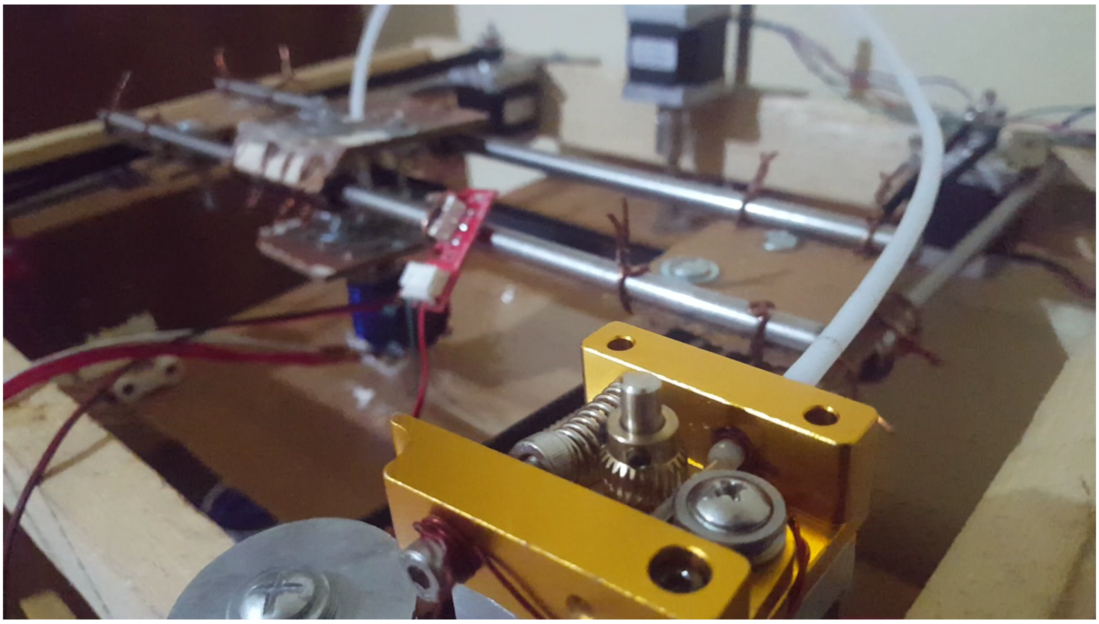

Figure 4.4: After mounting the extruder

- **Remark:** The extruder can be installed on top of the printing head to directly drive the filament into it, but in our case, we haven't installed it this way because it would add unnecessary extra mass to the moving components of the printer which will over load the motors

4.1.2 First 3D Print test

First we design a test object with Designspark mechanical as shown in Figure 4.5.

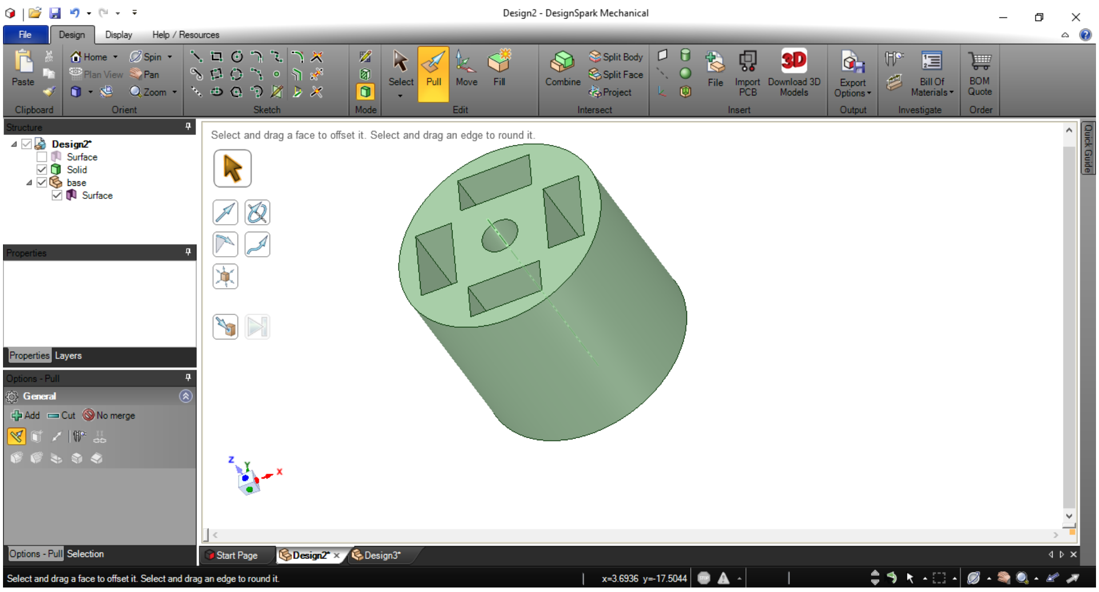

Figure 4.5: Test model 3d design

4.1.2.1 Slicing software

Slic3r is free software and a 3D slicing engine for 3D printers. It generates G-code from 3D CAD files. Once finished, an appropriate G-code file for the production of the 3D modeled part or object is sent to the 3D printer for the manufacturing of a physical object.[wik]

Figure 4.6 shows the user interface of the used slicing software

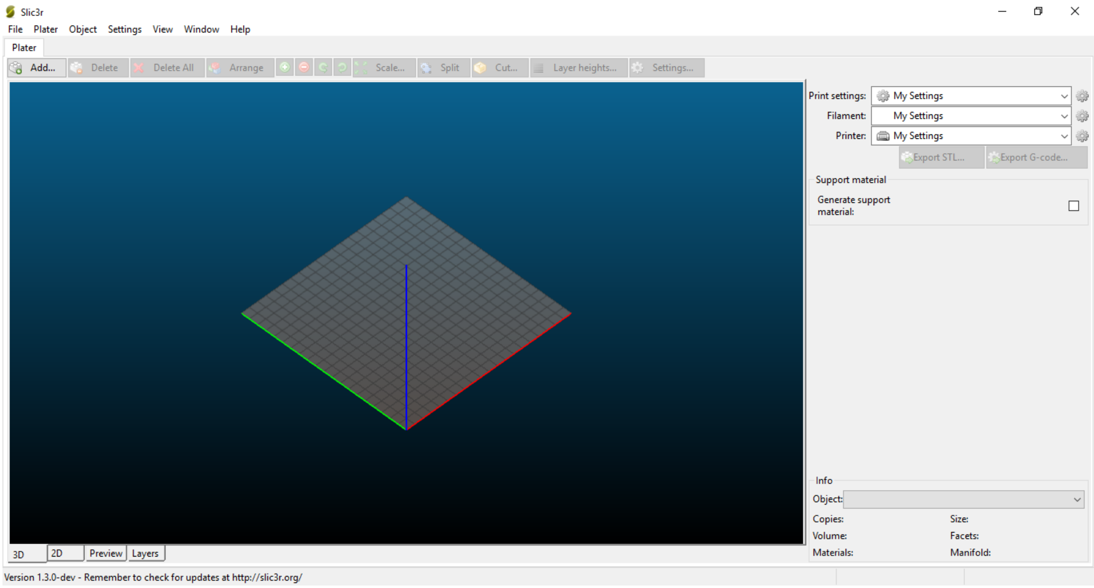

Figure 4.6: Slic3r 3D user interface

- **Remark:** G-code is the common name for the most widely used numerical control programming language. It is used mainly in computer-aided manufacturing to control automated machine tools. G-code is a language in which people tell computerized machine tools how to make something.[gco]

After exporting the designed model from the CAD software, now we open this exported file in a slicing software to generate motion paths for each layer out of the 3d model as shown in Figure 4.7 so we can export it as a G-code file.

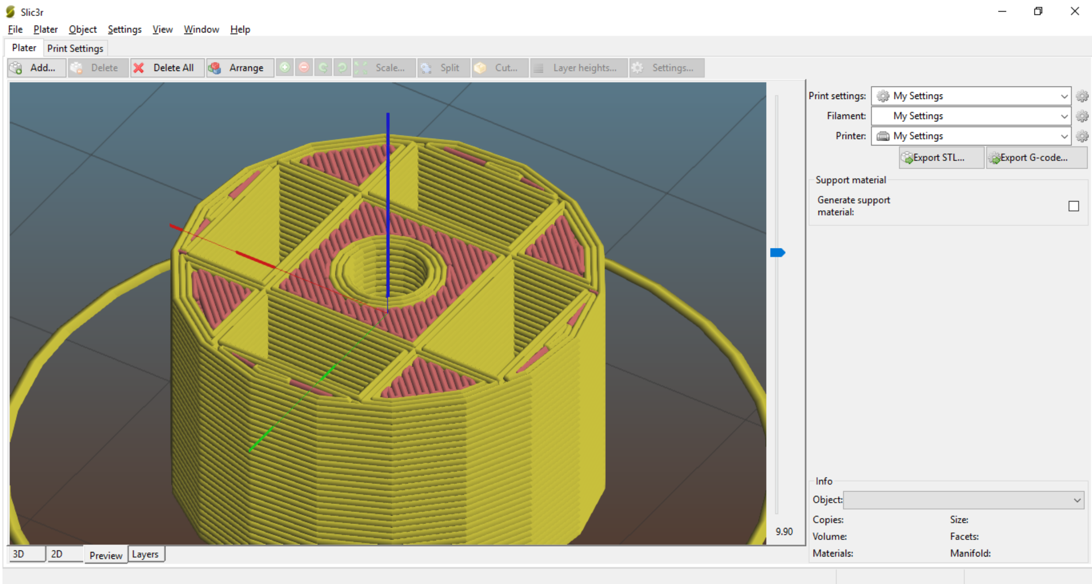

Figure 4.7: Slicing the 3d model using Slic3r

4.1.2.2 3D printing

After that, we import the exported G-code file into Pronterface as shown in Figure 4.8, this piece of software sends the G-code commands to the Arduino mega board for control the stepper motors as required.

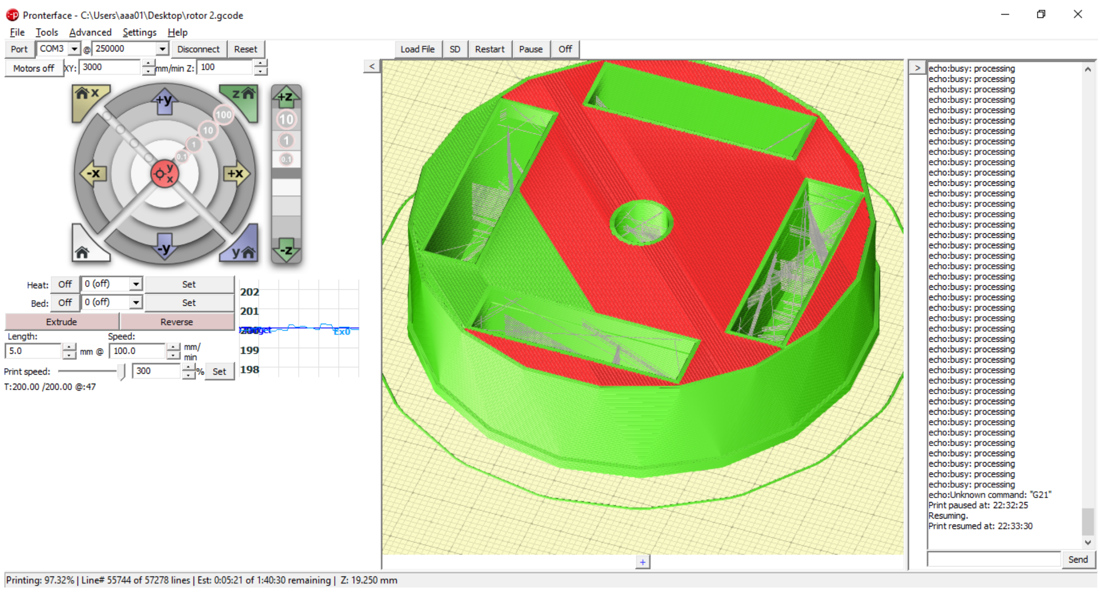

Figure 4.8: 3D Printing progress

- **Remark:** We could have used the SD card reader of the LCD display to send the G-code data to the Arduino mega board, we used this software to better visualize the process.

Figure 4.9 is the result we achieved after the printing process is finished.

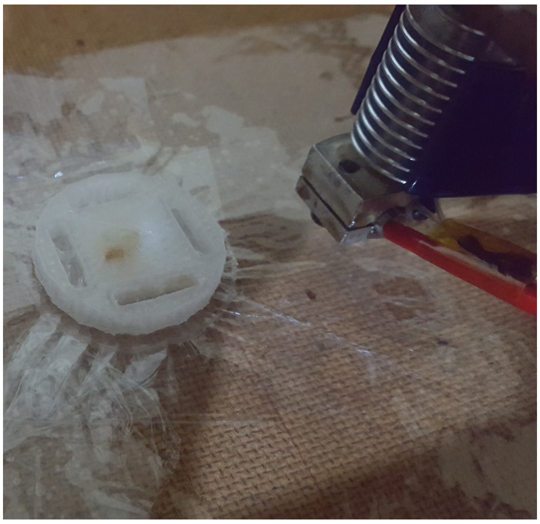

Figure 4.9: First 3D print test

The same process is repeated with another test object, the achieved result is shown in Figure 4.10

Figure 4.10: 3D print sample

- **Remark:** 3D printing with fused filament fabrication technology takes long time, the first 3d sample took approximately two hours to print, the second one took longer than four hours.

4.2 Second build

More rigid frame and mechanical components mean higher 3D printing accuracy and overall better performance. This was the main reason behind deciding to disassemble the first machine as shown in Figure 4.11 and use its components for a second build.

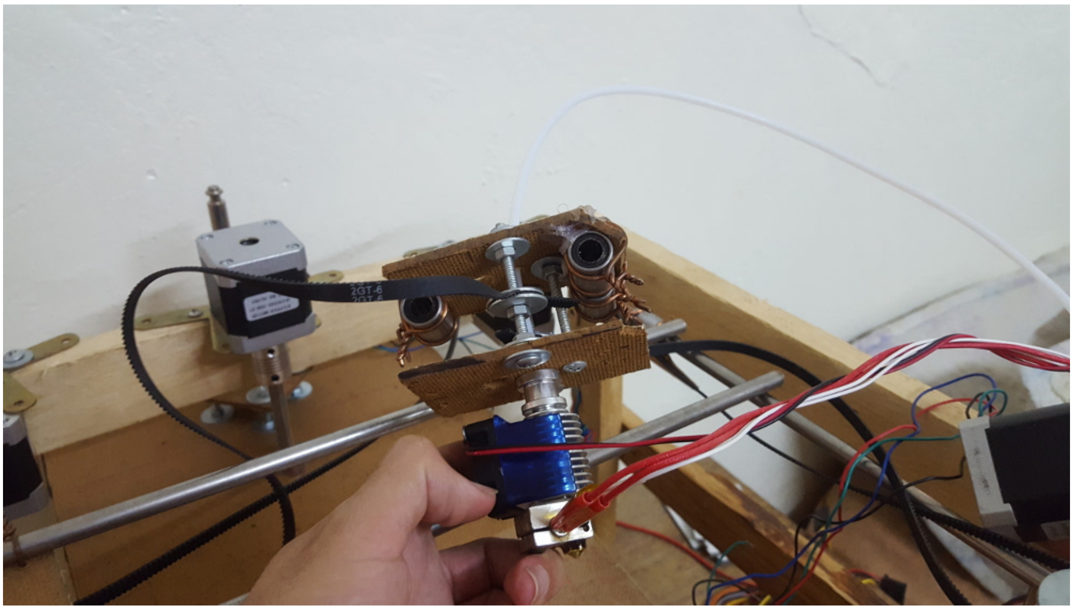

Figure 4.11: disassembly of the wooden frame printer

4.2.1 Assembling and mounting parts of the new machine

Figure 4.12 shows the start of the rebuild of the machine using aluminum instead of wood.

Figure 4.12: assembling aluminum frame

Figure 4.13 shows the top view of X axis movement components.

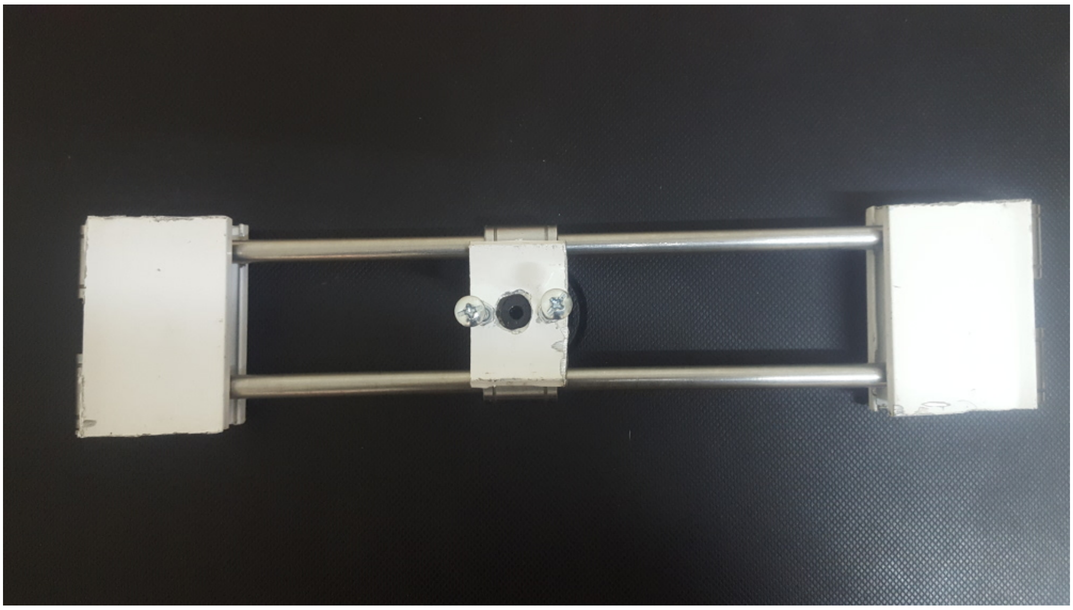

Figure 4.13: top view of the X axis movement components assembled

Figure 4.14 shows the side view of X axis movement components, the two bolts will later be used as attaching points for the belt.

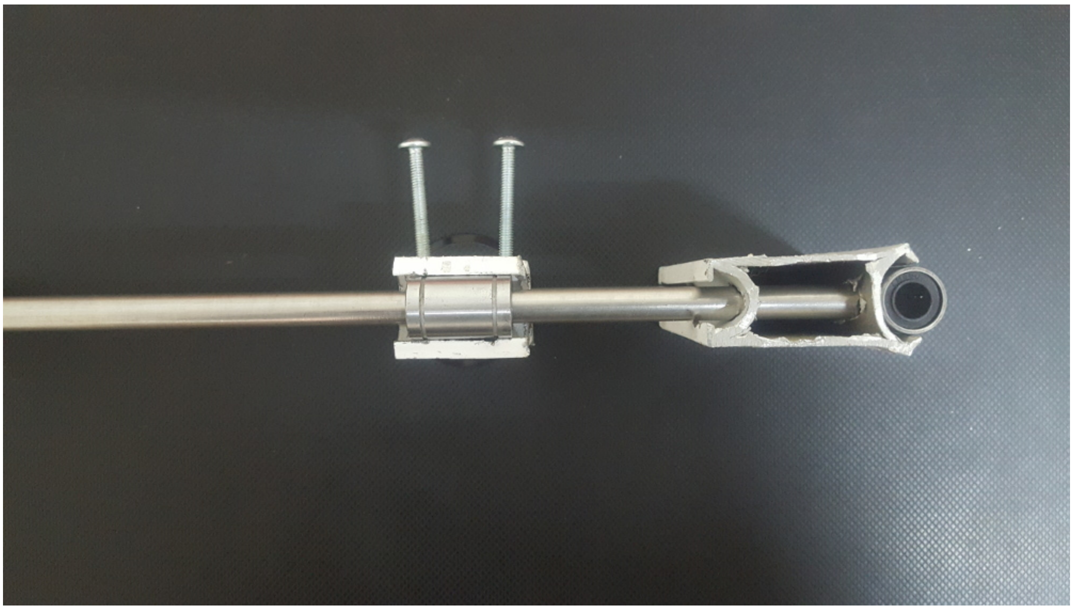

Figure 4.14: side view of the X axis movement components assembled

The belt mechanism we used requires bearings to be installedas shown in Figure 4.15, X and Y movement stepper motors where also mounted.

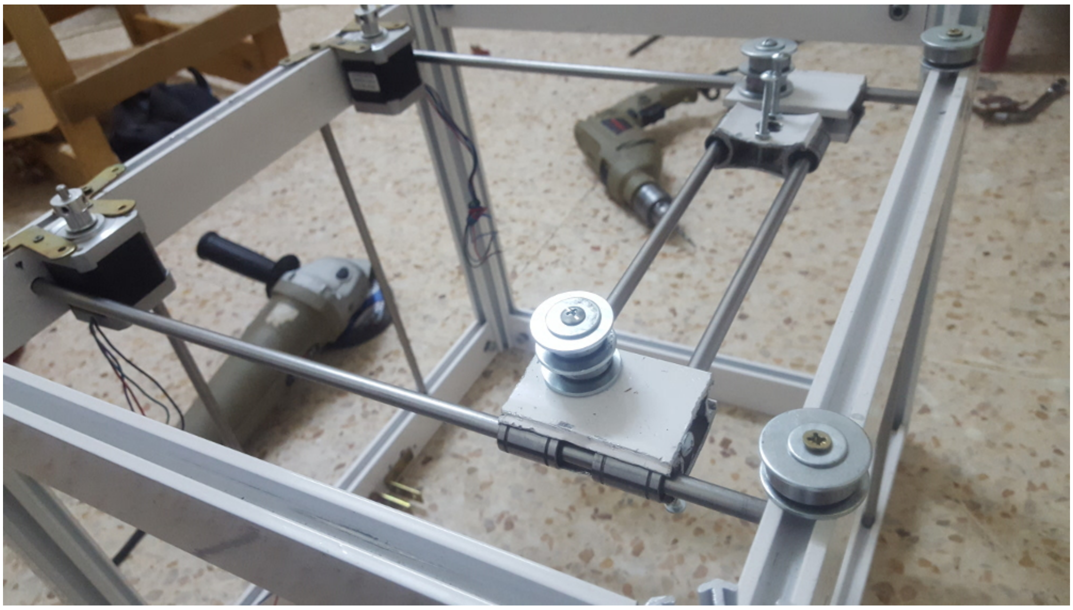

Figure 4.15: X and Y movement components

Figure 4.16 shows the top view after the assembly of most mechanical parts.

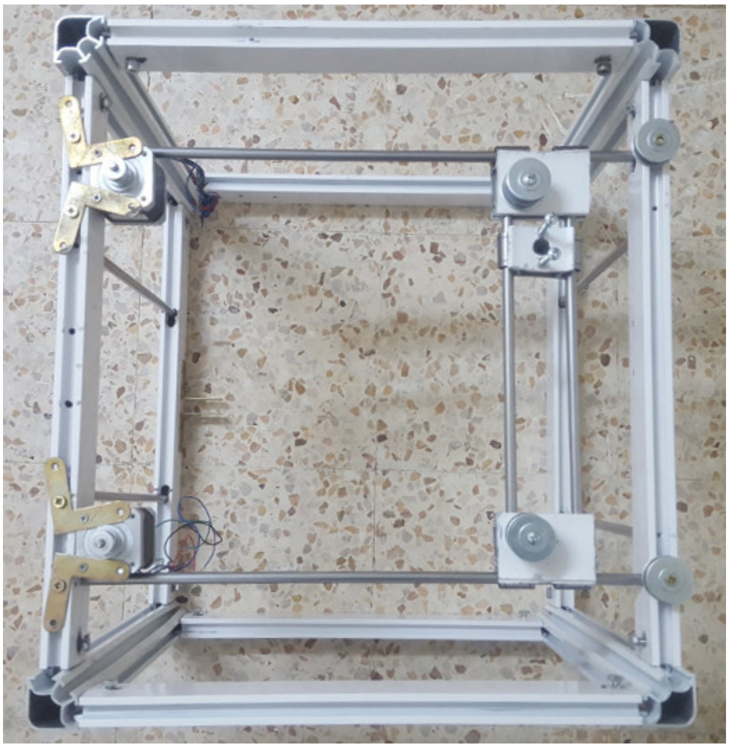

Figure 4.16: top view of the 3D printer after assembling metal parts

after mounting X and Y components, now the printing base should also be installed, it must have the ability to move accurately up and down along the Z axis as required, notice Figure 4.17 shows that the threaded rod and Z axis stepper motor were installed.

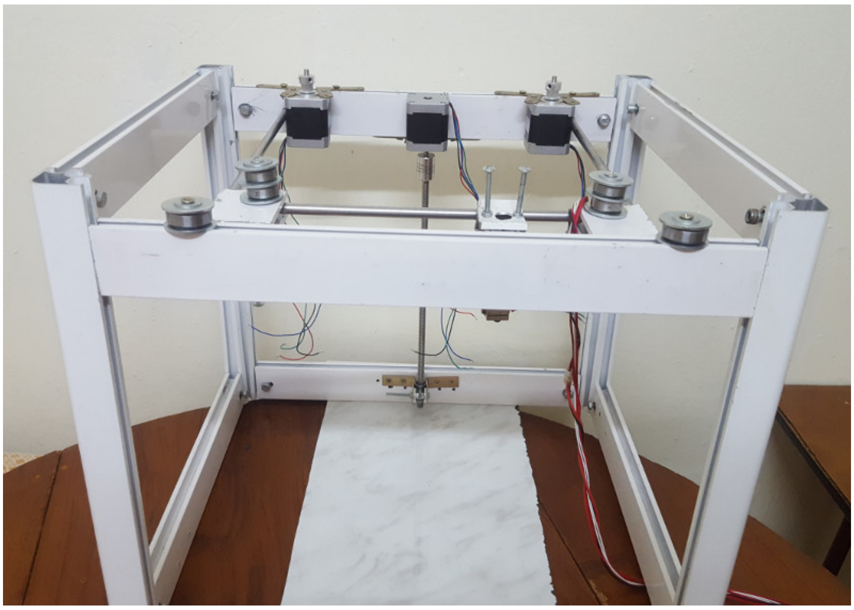

Figure 4.17: 3D printer view before mounting the printing base

The rotating motion of the threaded rod causes the printing base to rise or descend, but it can also rotate unless we constrain this motion,for this purpose we will use two metallic smooth rods to guide the Z axis motion of the base and prevent the unwanted rotation.

Figure 4.18: Determining drill points for Z axis guiding rods

Before drilling holes for the guiding rods, we should first determine their locations, Figure 4.18 is a top view that shows the location where the guiding rods will be installed.

Figure 4.19 shows the machine after installing the base and the motion belt.

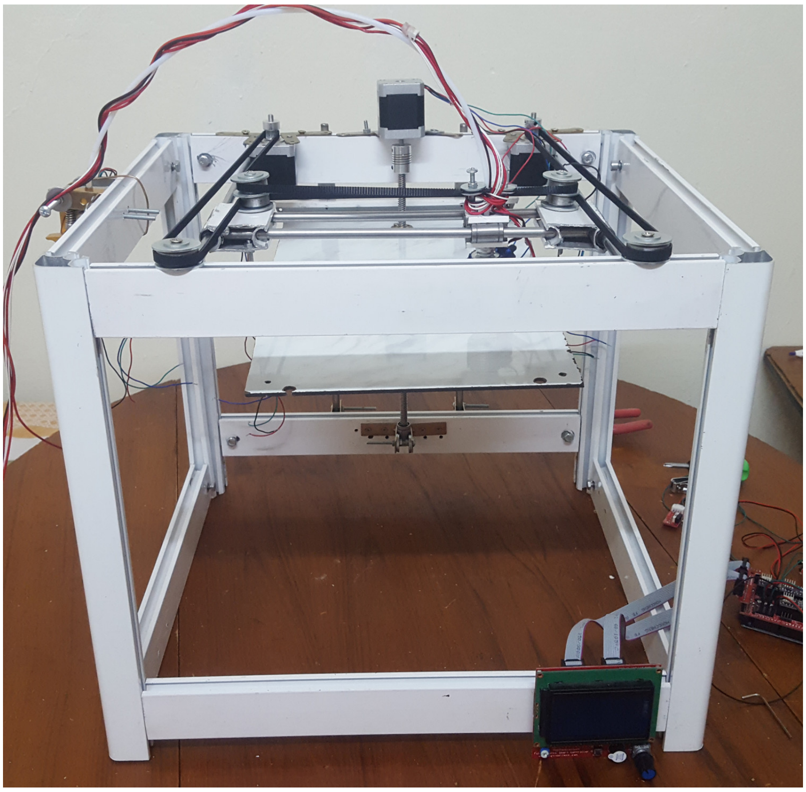

Figure 4.19: 3D printer view after mounting the printing base

After assembling the printer, now we connect the electronic components as shown in Figure 4.20, to power up the machine we use 12 volts DC power supply.

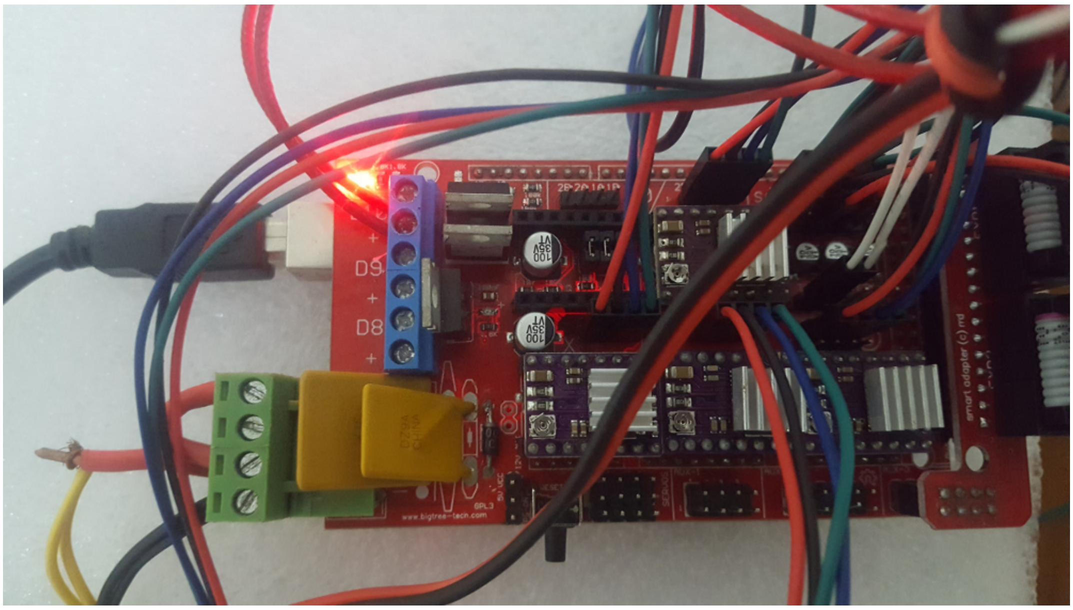

Figure 4.20: Wiring of the 3D printer electronic components

From a side view we noticed a slight tilt of the base as shown in Figure 4.21, this tilt is caused due to the weight of the printing base, this problem will make it very difficult for the first 3D Printing layer to stick uniformly, and even if it does, the final print will have distorted geometry.

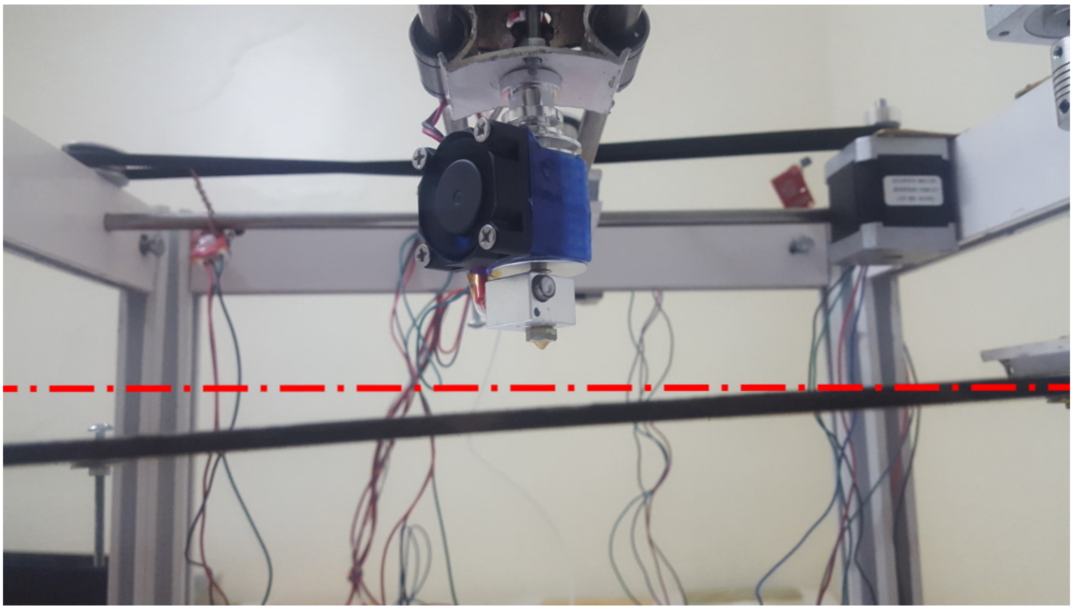

Figure 4.21: Tilted printing base side view

In order to straighten the printing base, one of the solutions we could have used is an additional Z axis motor on the other side of the base, and have both Z axis motors motion synchronized, but the easiest and most feasible solution was to use binding wire as shown in 4.22

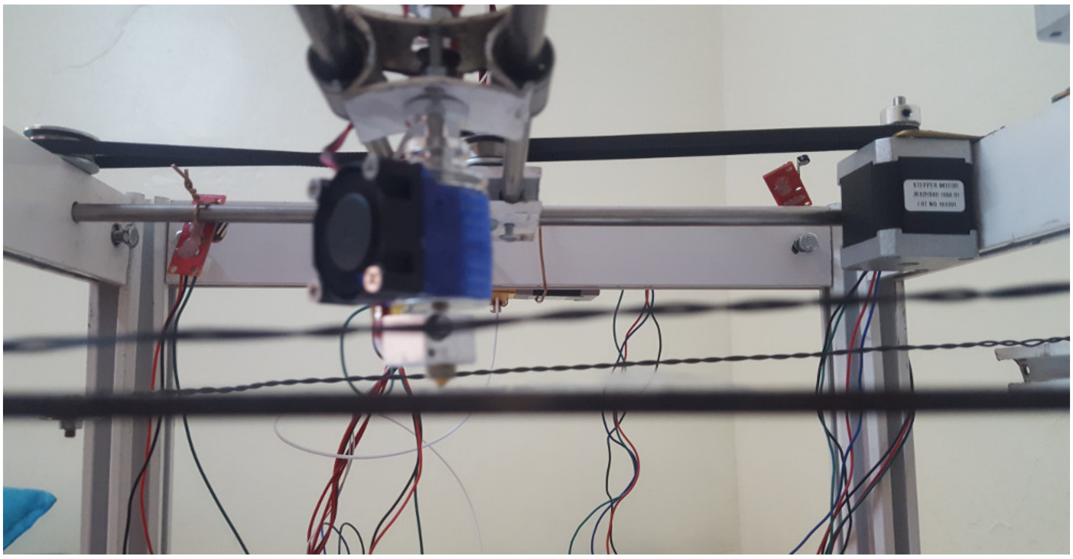

Figure 4.22: Printing base after fixing the tilt problem

4.2.2 From 3D design to 3D object

After assembling all necessary 3D Printer components, now we will go through the steps from modeling a 3d object to actually 3D printing it using this machine.

4.2.2.1 Designing a 3d model

To hold the end-stops to their linear rods, we are using a small piece of copper wire, it does hold the end-stops but not as tight as required, therefore we want to 3D Print a holder for the end-stops to replace the copper wires which we are currently using.

Using design spark mechanical we first start by sketching a circle with eight millimeters in diameter.

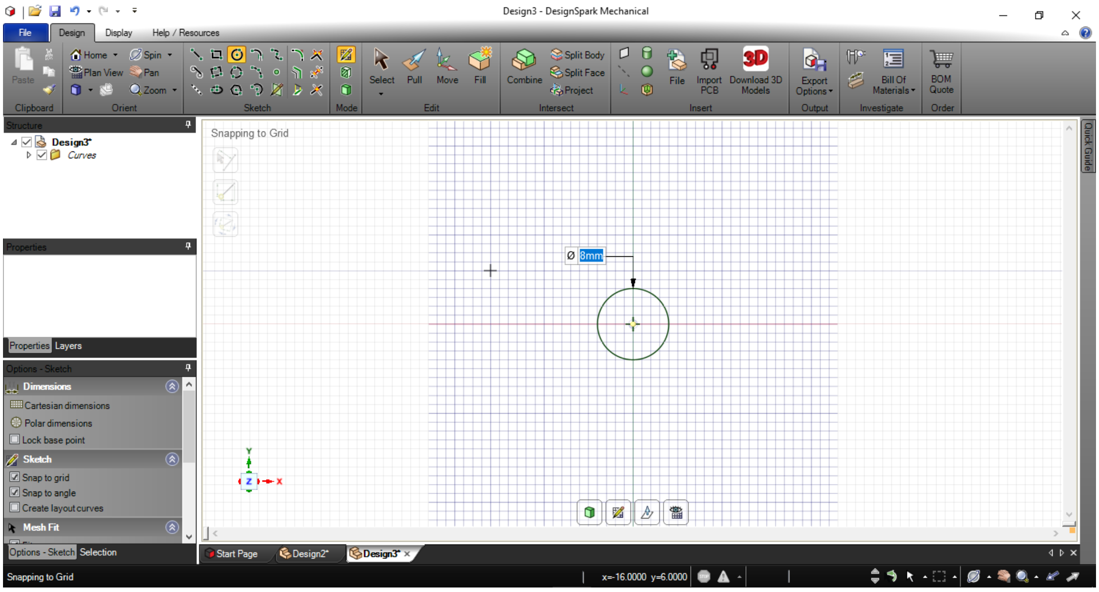

Figure 4.23: sketching circle 8 mm diameter

Then we sketch guidelines to determine the right distance for the screw holes of the holder as shown in 4.24.

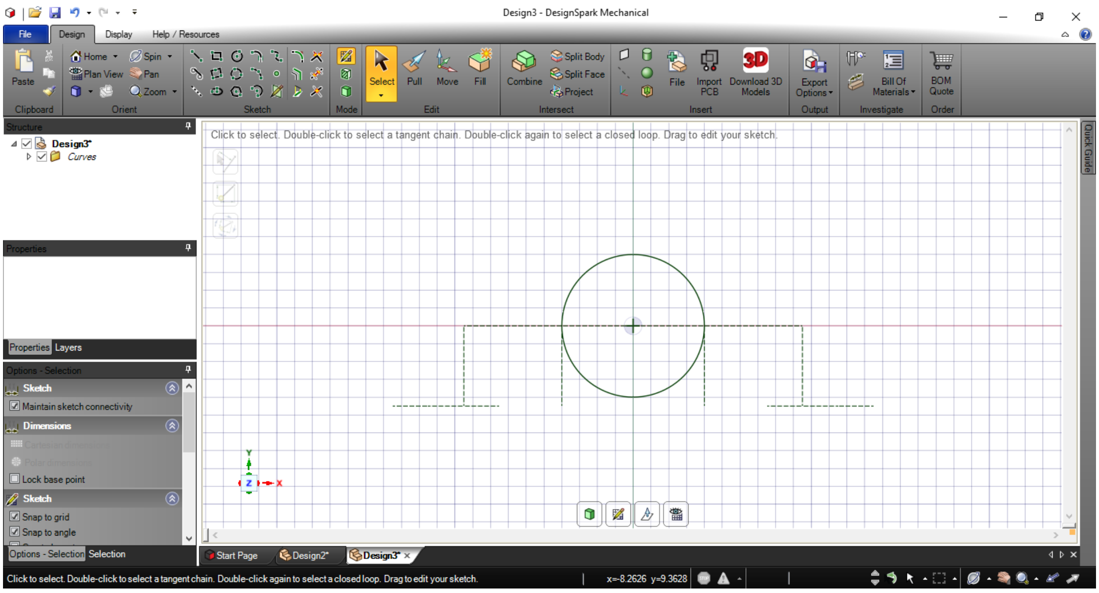

Figure 4.24: sketching guidelines

After that we start drawing the outer lines as shown in Figure 4.25

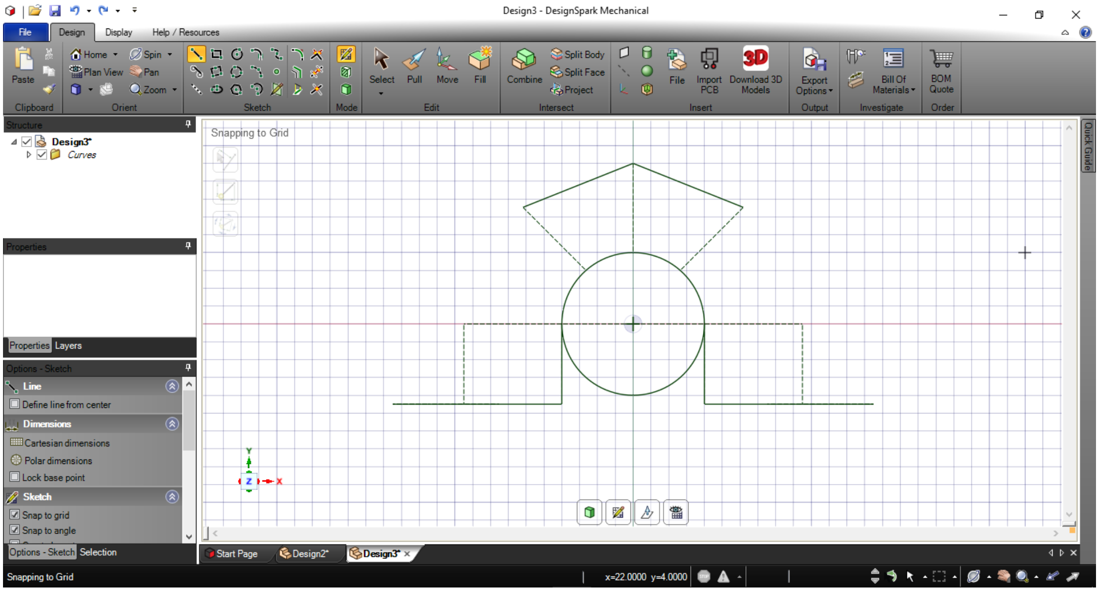

Figure 4.25: sketching the geometry of the end-stop holder

Figure 4.26 shows the final 2d sketch of the design.

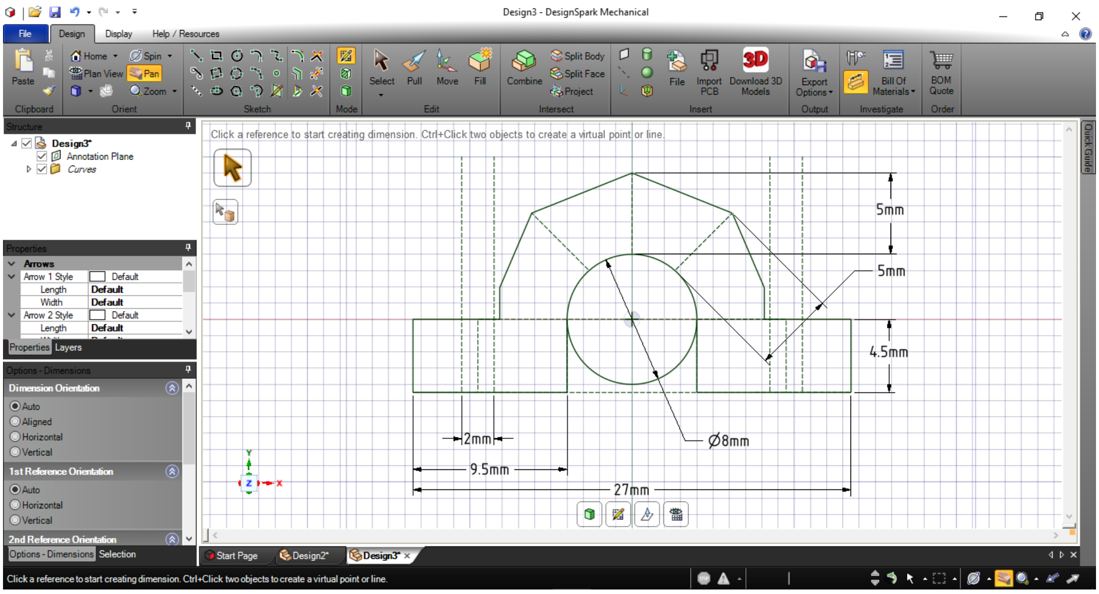

Figure 4.26: final geometry of the end-stop holder with lengths

After that we make a six millimeters extrusion from the sketch to make our 3d model.

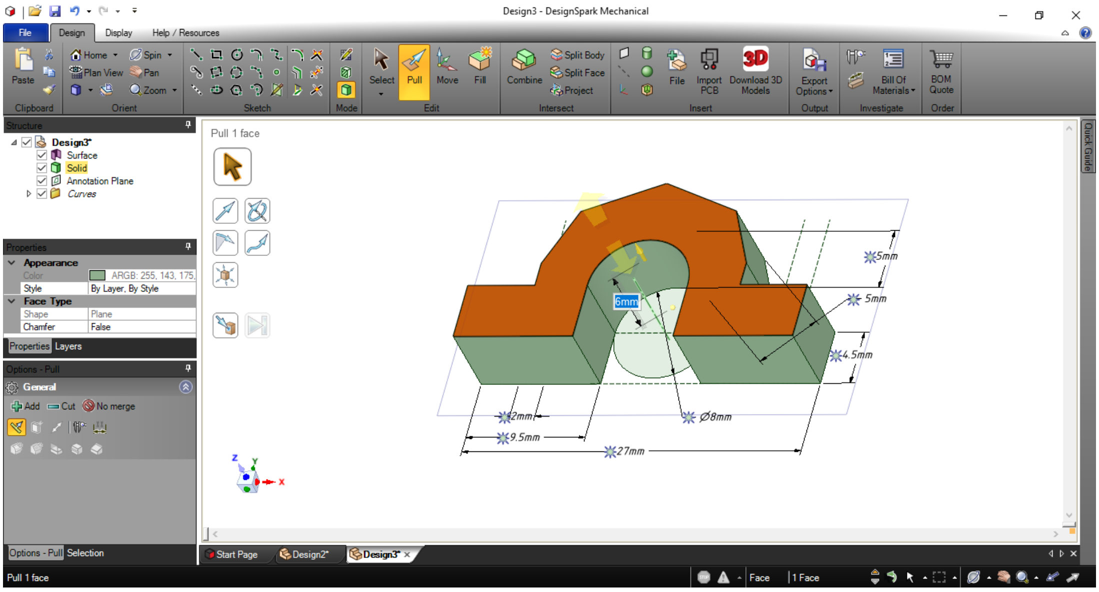

Figure 4.27: extruding the the sketch

Next we sketch two circles of 2 millimeters in diameter on each side of the holder 4.28, then we preform a reverse extrude to subtract two cylinders from the object to form holes for the bolts.

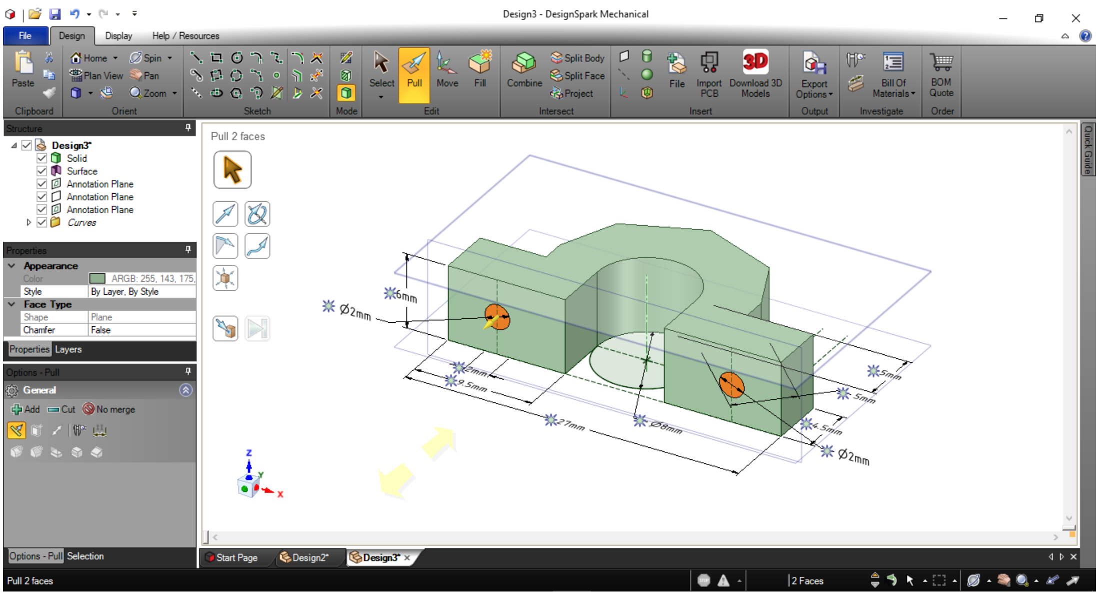

Figure 4.28: making holes for the end-stop holder

Figure 4.29 shows the result of the reverse extrusion preformed recently.

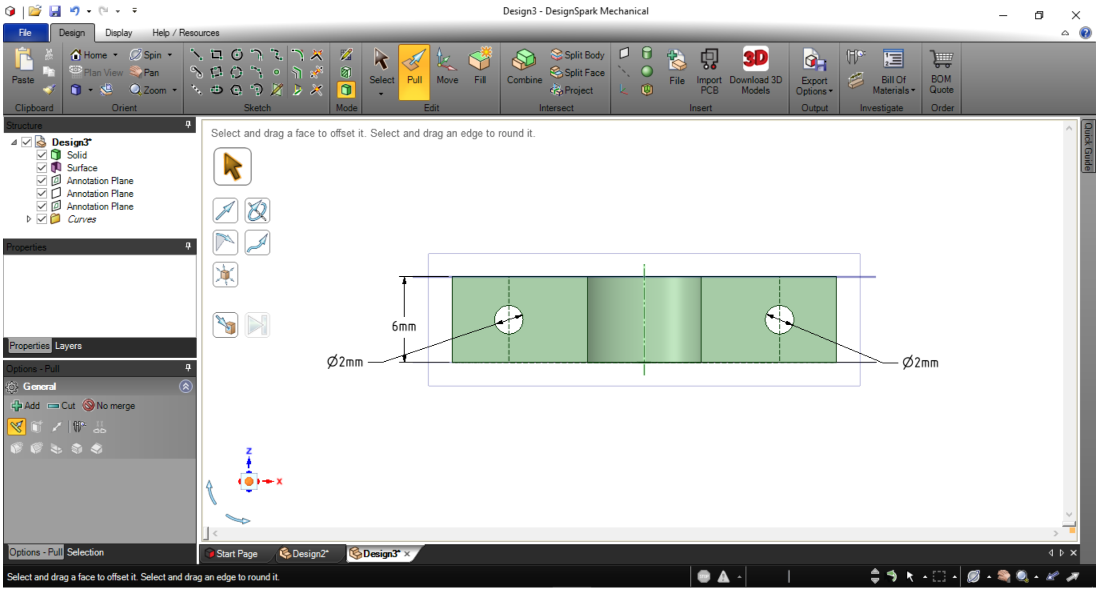

Figure 4.29: side view of the end-stop holder

Finally, after finishing our 3d design, we export it in STL format. Figure 4.30 shows top, front, side and perspective view of the designed model :

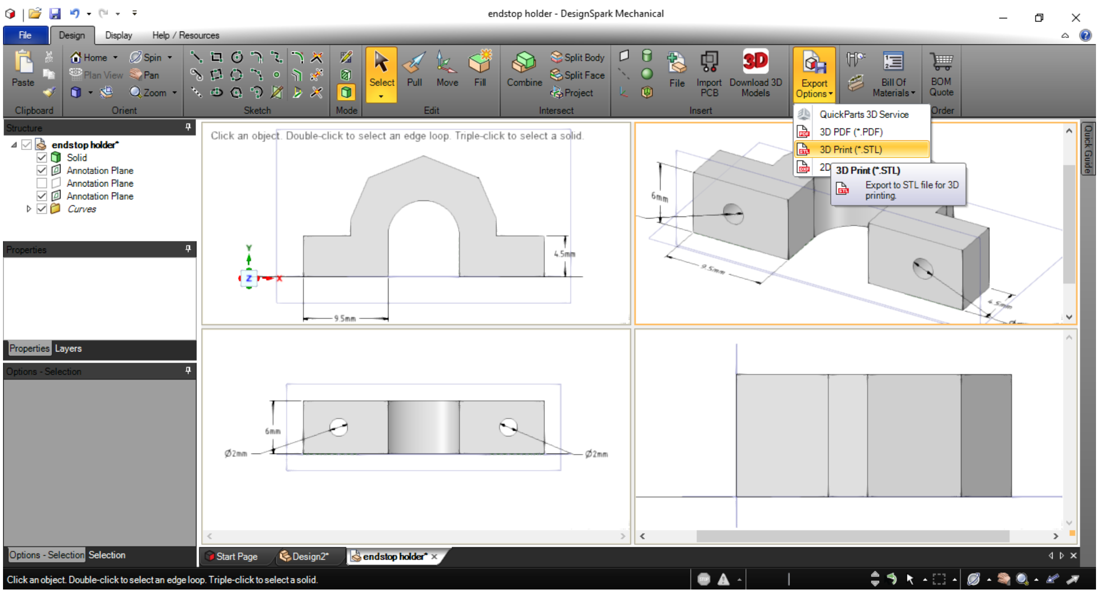

Figure 4.30: exporting the model as an STL file

4.2.2.2 Slicing the 3d model

After exporting the 3d model in STL file format, now we will open it using the same slicing software we used in the first build. Figure 4.31 shows the imported model in slic3r.

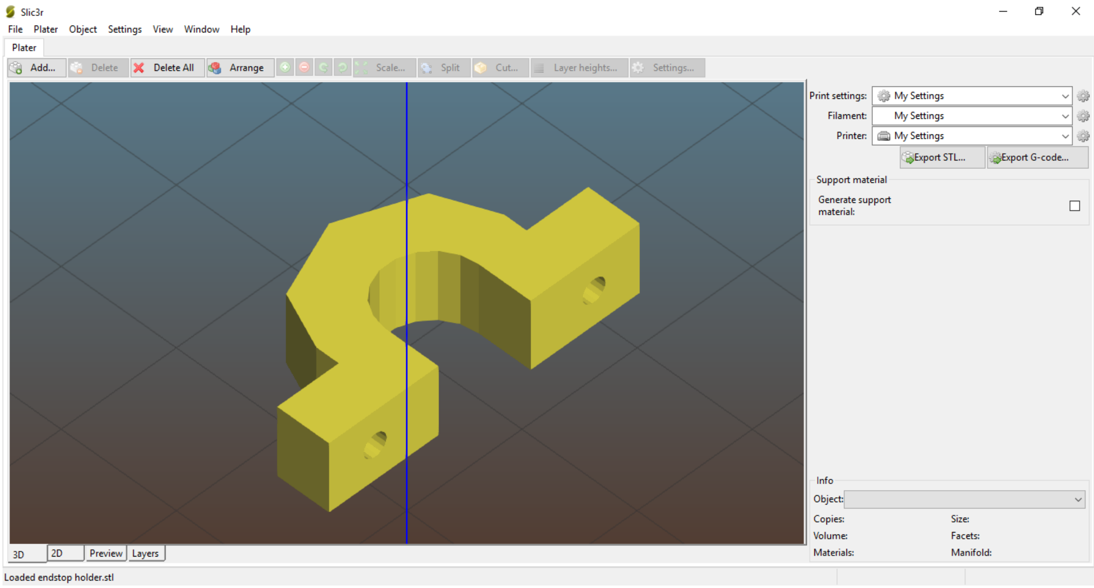

Figure 4.31: importing the model to Slic3r

Before exporting the G-code file, we can adjust some parameters like:

- **Layer height:** Decreasing layer height will increase the print quality but it would also take longer time for the print to finish. 4.32 shows the layer and perimeters settings. We have set the layer height for all layers to be 0.3mm which is the same as the nozzle diameter

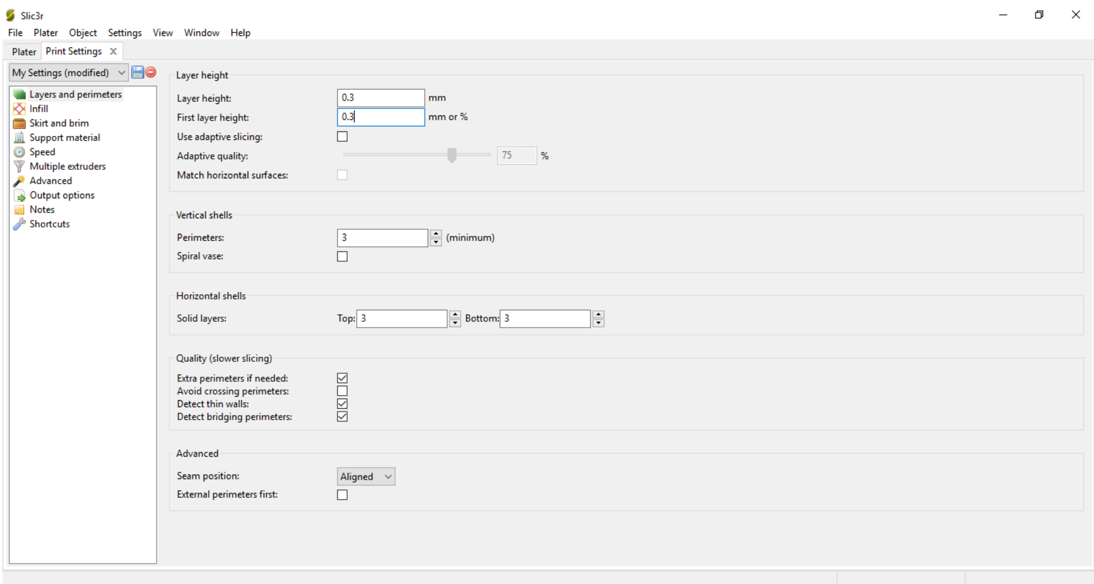

Figure 4.32: layer and perimeters settings

- **Infill:** In 3D printing, the term "infill" refers to the structure that is printed inside an object. It is extruded in a designated percentage and pattern, which is set in the slicing software. Infill percentage and pattern influence print weight, material usage, strength, print time and sometimes decorative properties.[inf]

4.33 shows the infill settings. We have set the infill percentage to be only 5% , this will result the inner volume of the printed object to be 95% hollow.

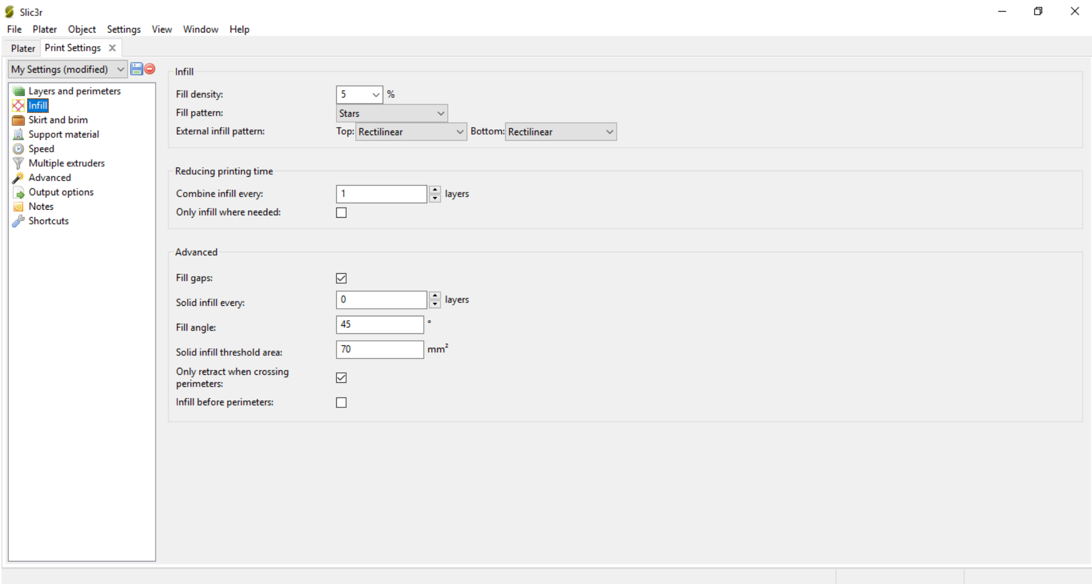

Figure 4.33: infill settings

- **Speed:** we can also adjust speed parameters by increasing or decreasing it, high speeds result in short printing time but will also decrease quality.

  4.34 shows the speed settings page. Here we set the speed during each of the following portions of the print to 60mm/s:

- **Perimeters**
- **Infill**
- **Bridges**
- **Support Material**

- **Remark** Since speed for non-print moves doesn't require laying down material, it was set to 130mm/s, almost twice the speed for print moments. We also have set the speed down to 20mm/s, in order for the first layer to stick firmly to the printing base.

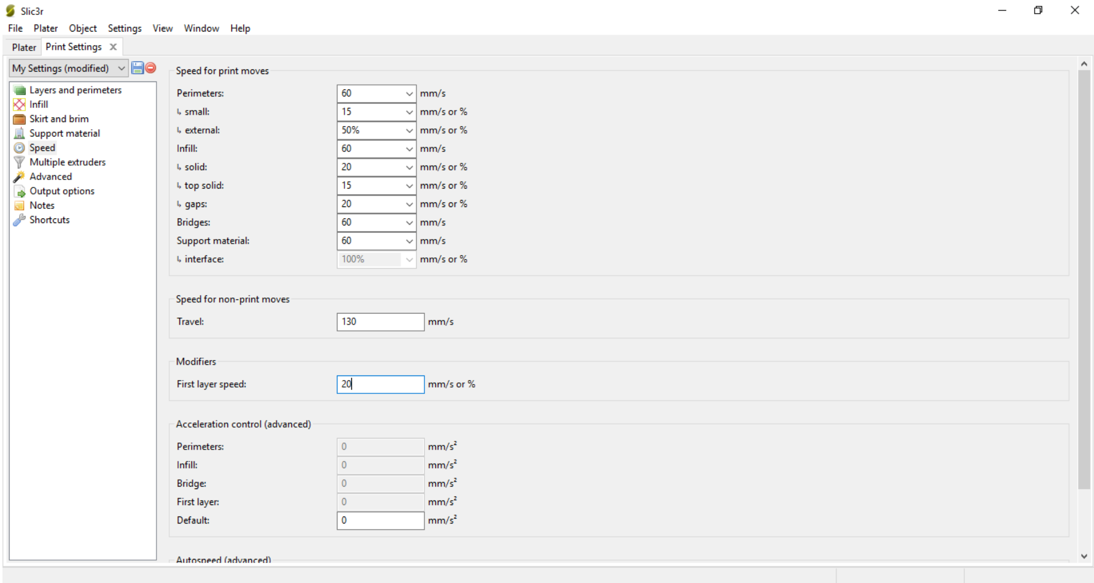

Figure 4.34: Speed settings

The slicing software we used allows us to take a look at each layer in preview mode, Figure 4.35 shows the first layer for the 3D object.

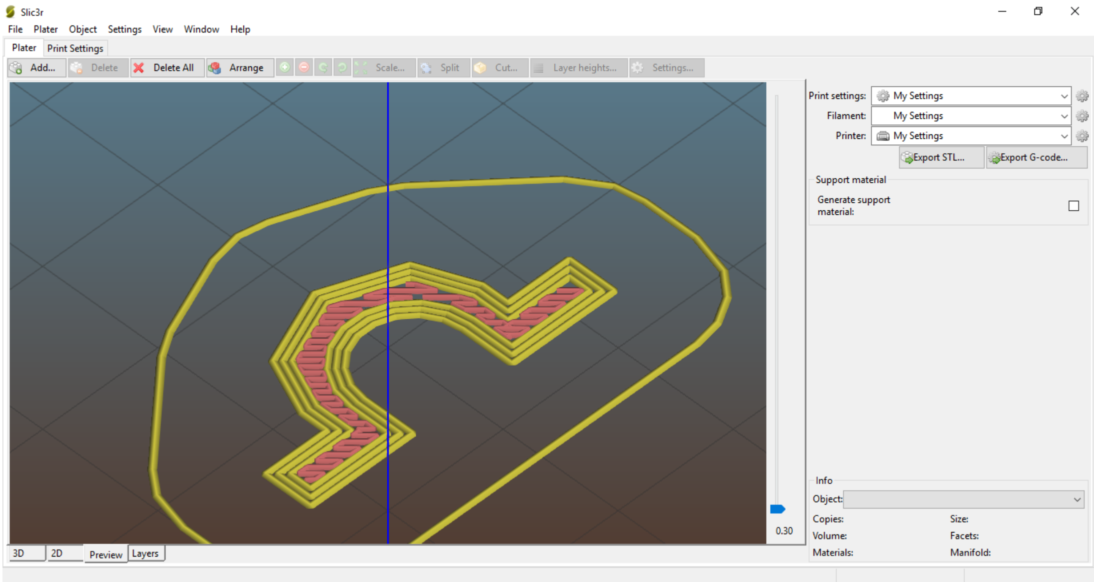

Figure 4.35: first layer for the 3D object in Slic3r

Figure 4.36 shows the second layer for the 3D object.

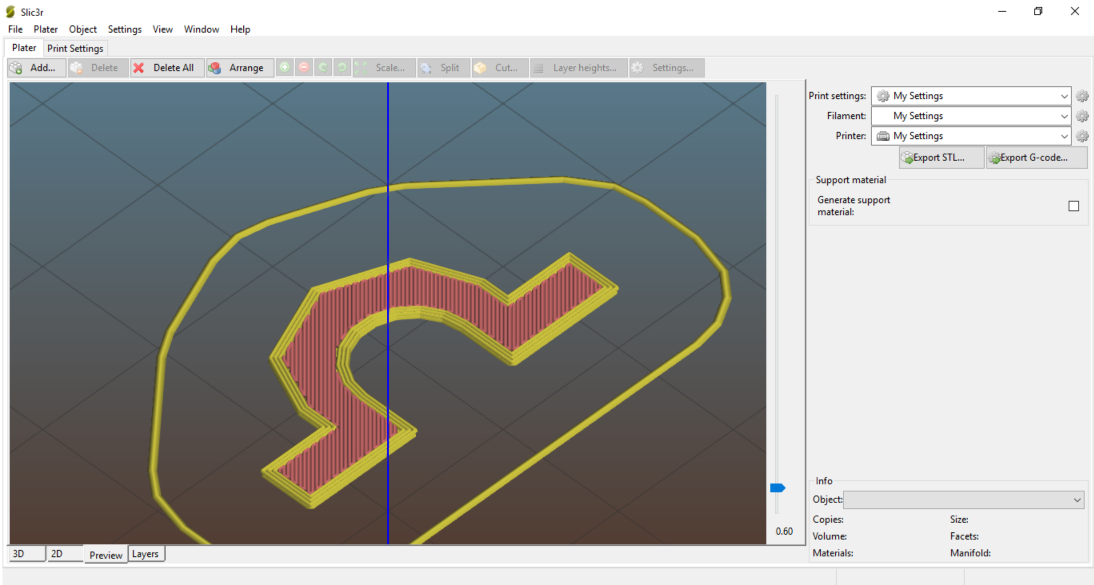

Figure 4.36: second layer for the 3D print in Slic3r

Figure 4.37 shows the middle layer for the 3D object.

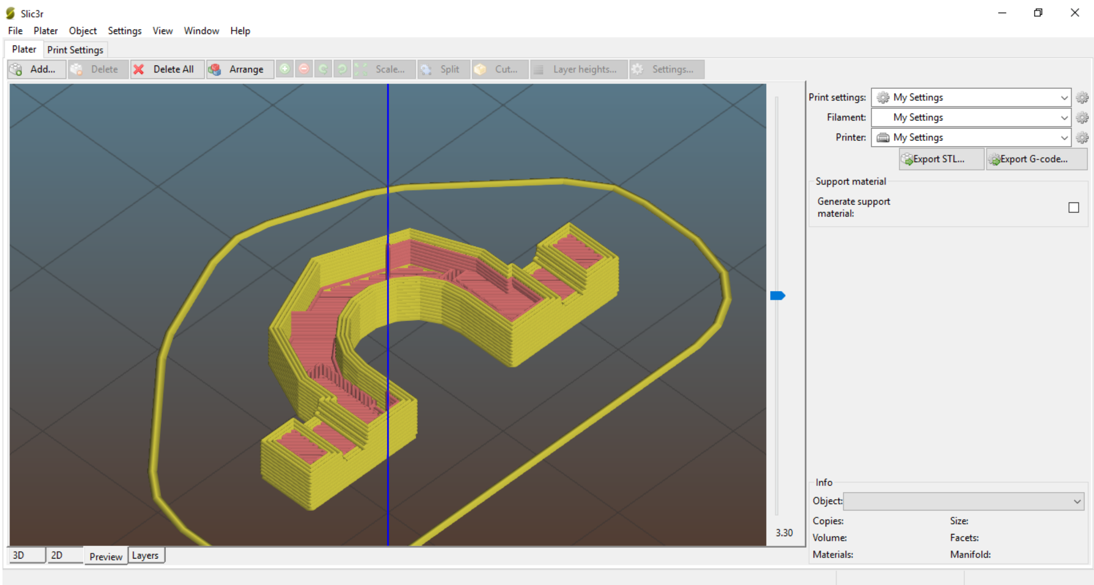

Figure 4.37: middle layer for the 3D print in Slic3r

Figure 4.38 shows the middle layer for the 3D object.

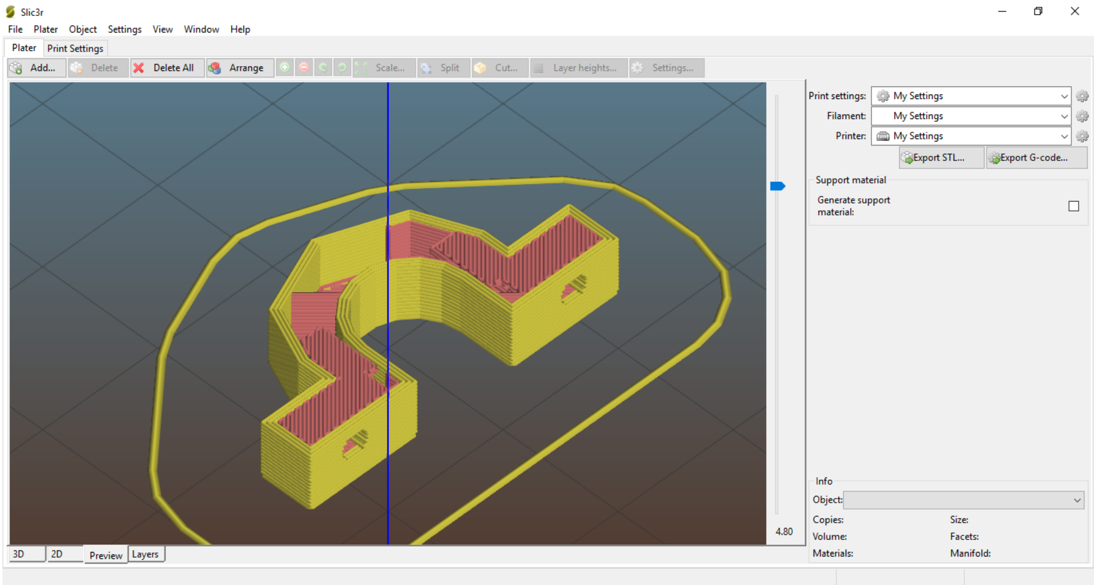

Figure 4.38: before final layer for the 3D print in Slic3r

Figure 4.39 shows the final layer for the 3D object.

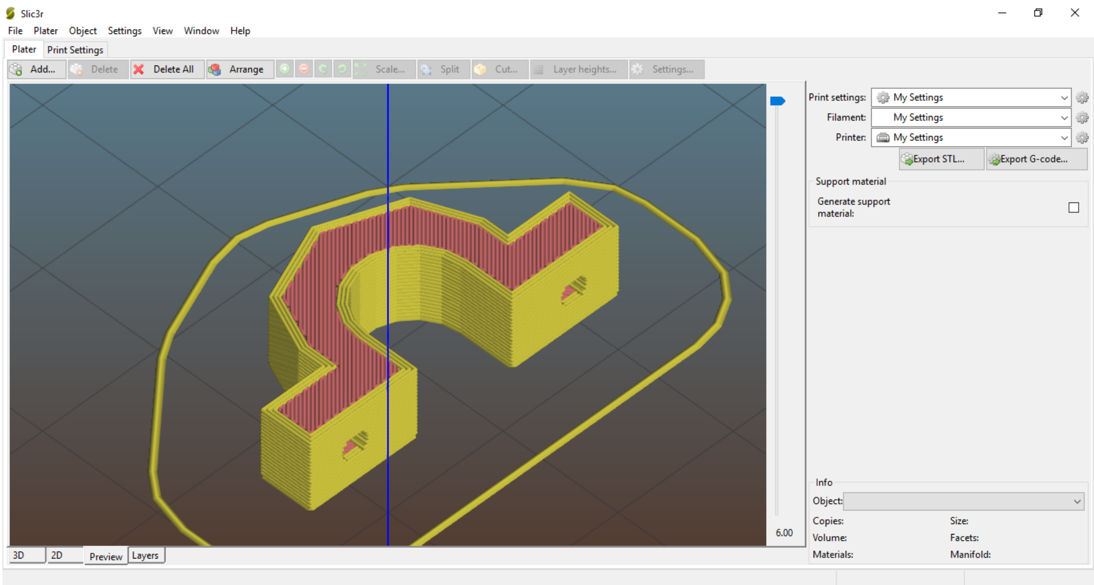

Figure 4.39: final layer for the 3D print in Slic3r

After adjusting the settings and verifying our object layers, now we will export the G-code file, Figure 4.40 displays our 3d model on Pronterface after importing the G-code file

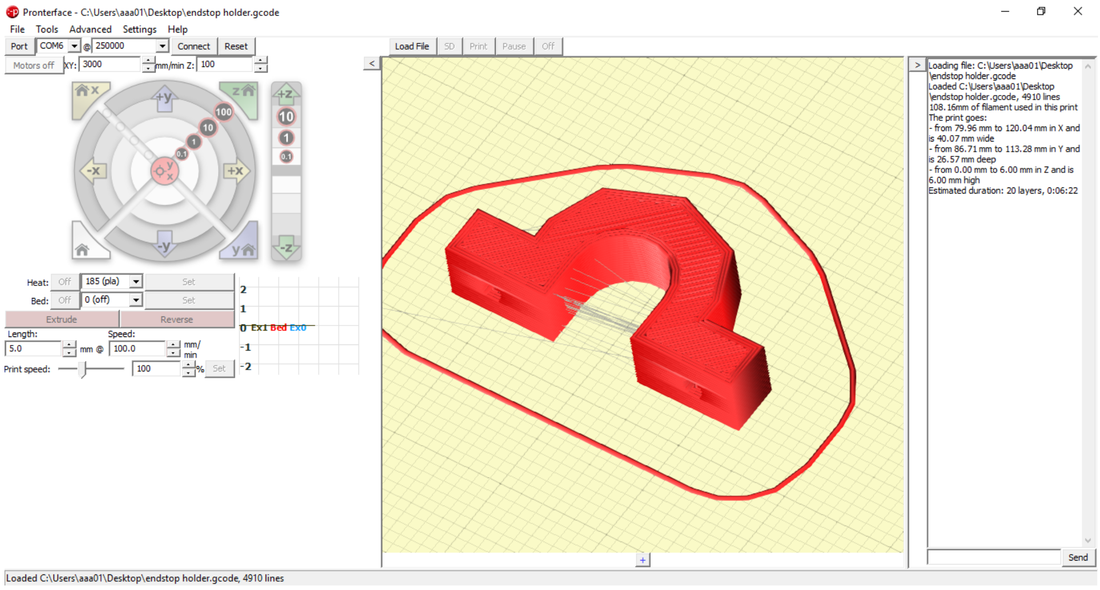

Figure 4.40: importing G-Code to Pronterface

4.2.2.3 3D printing the object

Before starting the 3D Printing process, the printing head travels to X0 and Y0 position, generally this position is referenced to as "home", Figure 4.41 shows the 3D Printing head after moving to X0 and Y0 position.

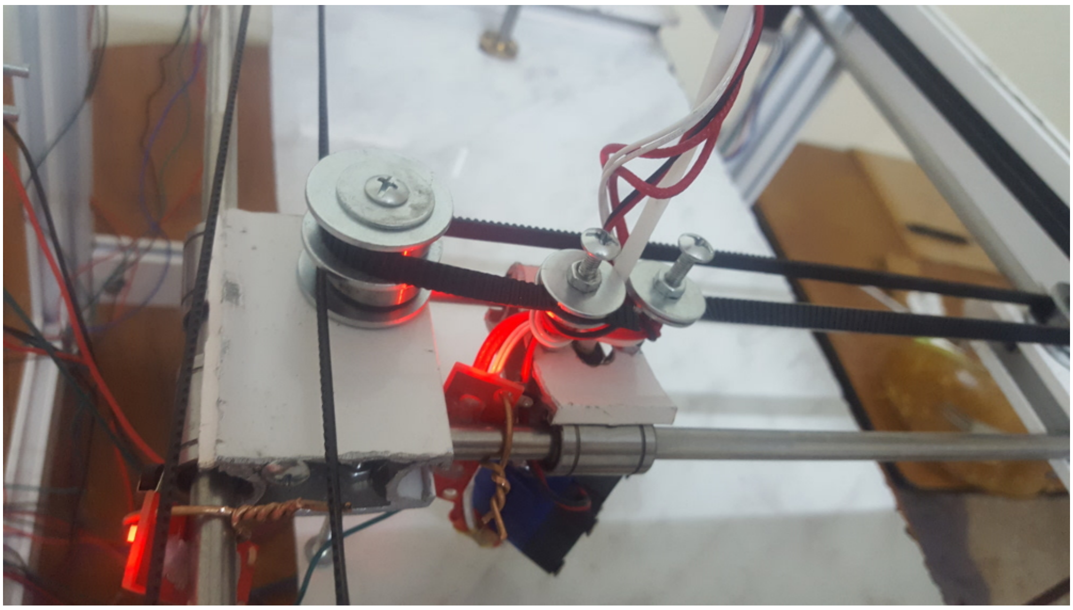

Figure 4.41: End-stops indicating home position at X0 Y0

After that, the printing head temperature increases until it reaches its reference temperature, notice in Figure 4.42 the reference temperature is 205°.

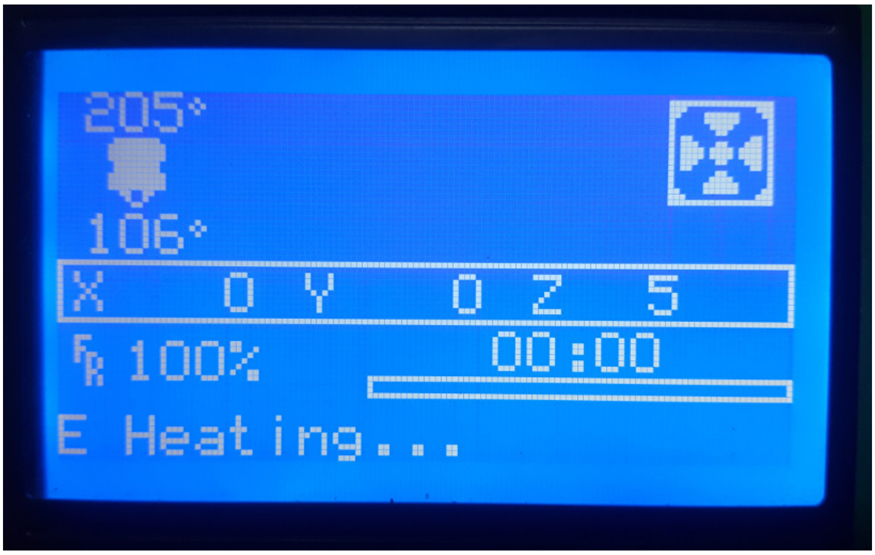

Figure 4.42: Heating the printing head

When the actual printing head temperature reaches the reference value, the Arduino mega board sends control signals according to the G-code commands generated earlier to the stepper drivers, in order to move the printing head and extrude the melted filament accordingly, after laying down the first layer, the Z axis stepper motor then rotates to lower the base with a distance equal to the value of layer height we set earlier, this process is then repeated for each layer until the 3D Print of the object is complete. Figure 4.43 shows the 3d object during 3D Printing process.

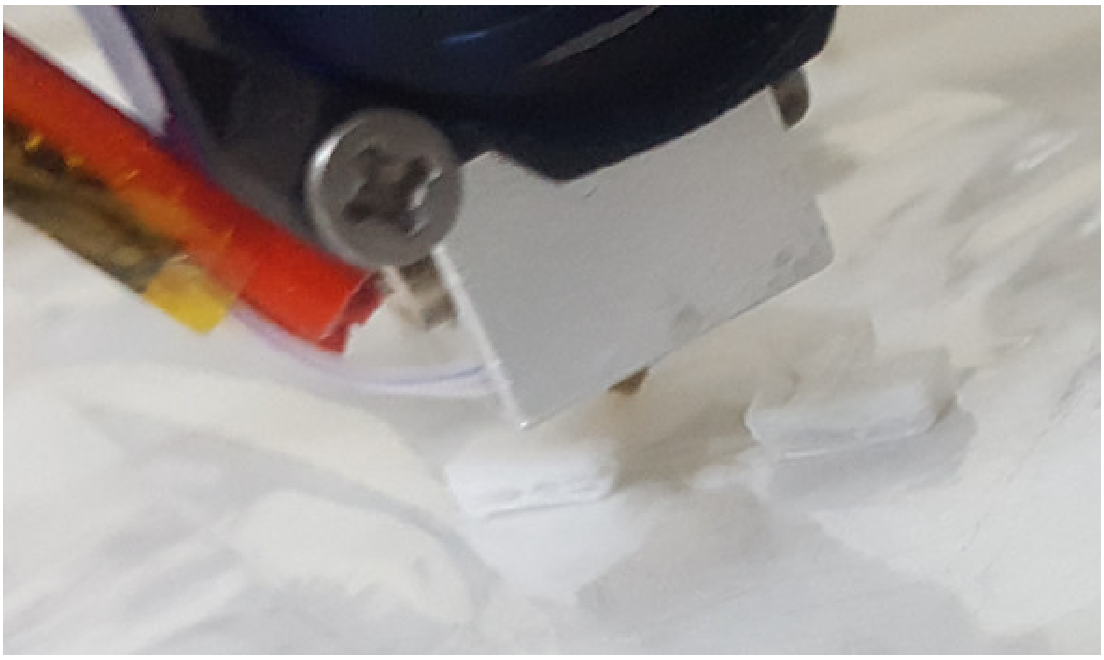

Figure 4.43: during end-stop holder 3D printing process

As we can see in Figure 4.44, the part of the model highlighted in green represents the already printed portion of the object, where as the part highlighted in red represents the remaining layers that are going to be printed next

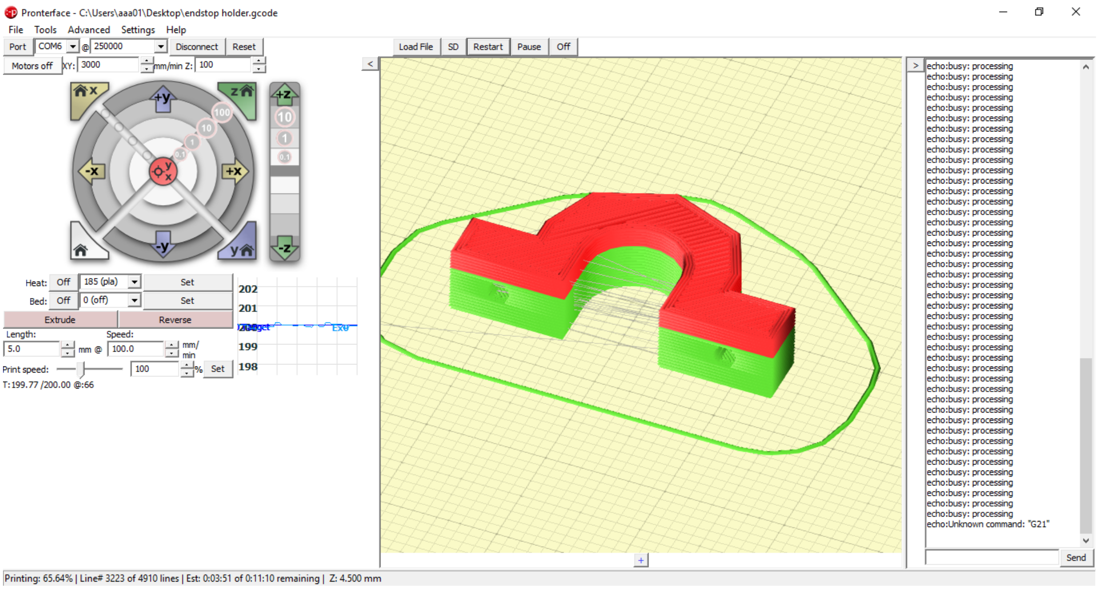

Figure 4.44: near finish printing progress as shown on Pronterface

And finally, Figure 4.45 shows the result we archived.

Figure 4.45: end-stop holder

As we can see in Figure 4.46 the printed object dimensions where 2mm to 3mm close to the dimensions of our 3d design, reducing this error requires readjusting the steps per unit parameters for the movement along the three axis, and also more ridge printer mechanical parts.

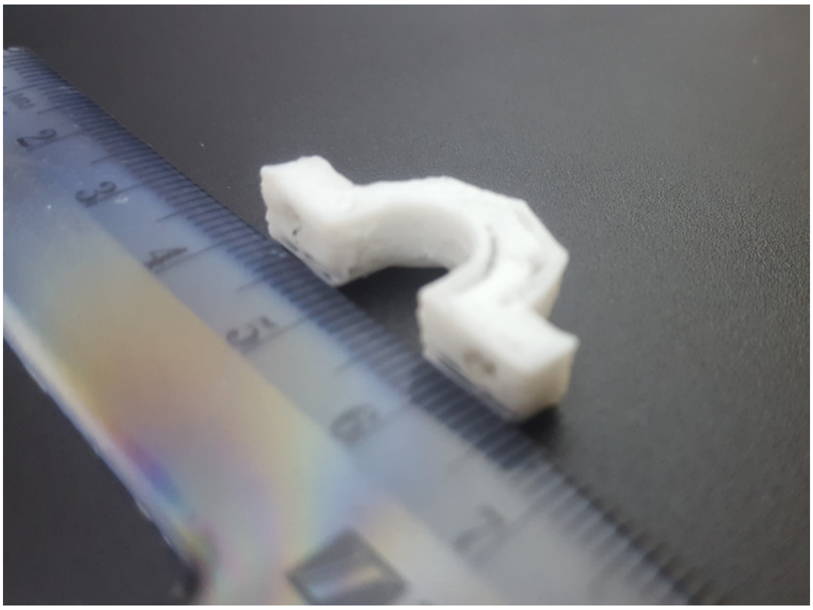

Figure 4.46: end-stop holder dimension accuracy check

- **Remark:** Although the object we designed was a relatively small object, the time it took to 3D Print it was approximately 16 minutes.

4.2.2.4 Using the 3D Printed object

Figure 4.47 shows how the end-stop was attached to the guiding rod before

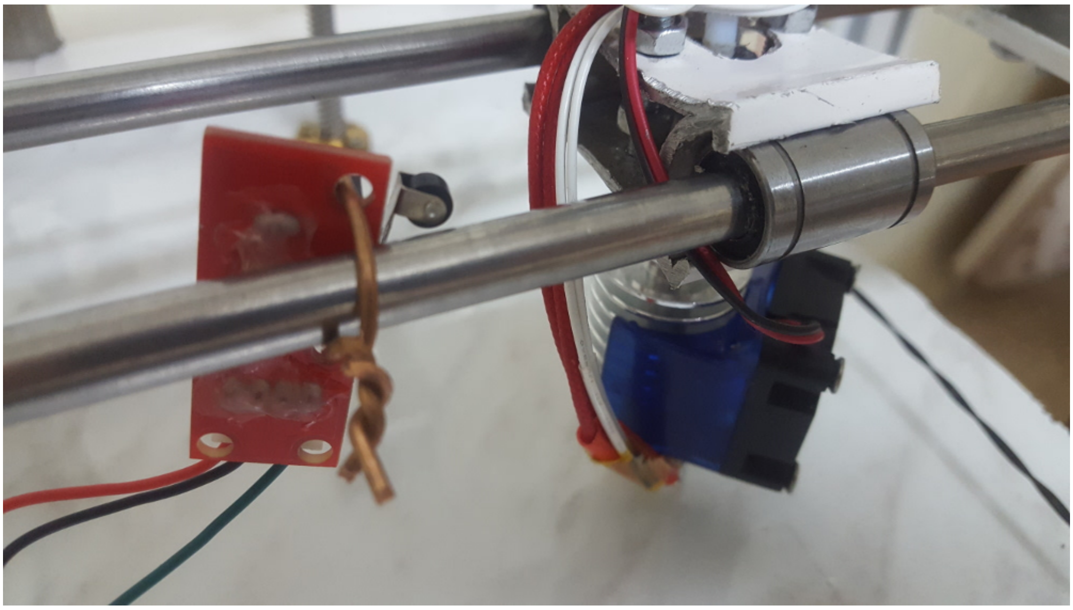

Figure 4.47: before using the 3D printed end-stop holder

Figure 4.47 shows how the end-stop is now attached using the 3D Printed piece, now it is held in place very well and can easily be readjusted :

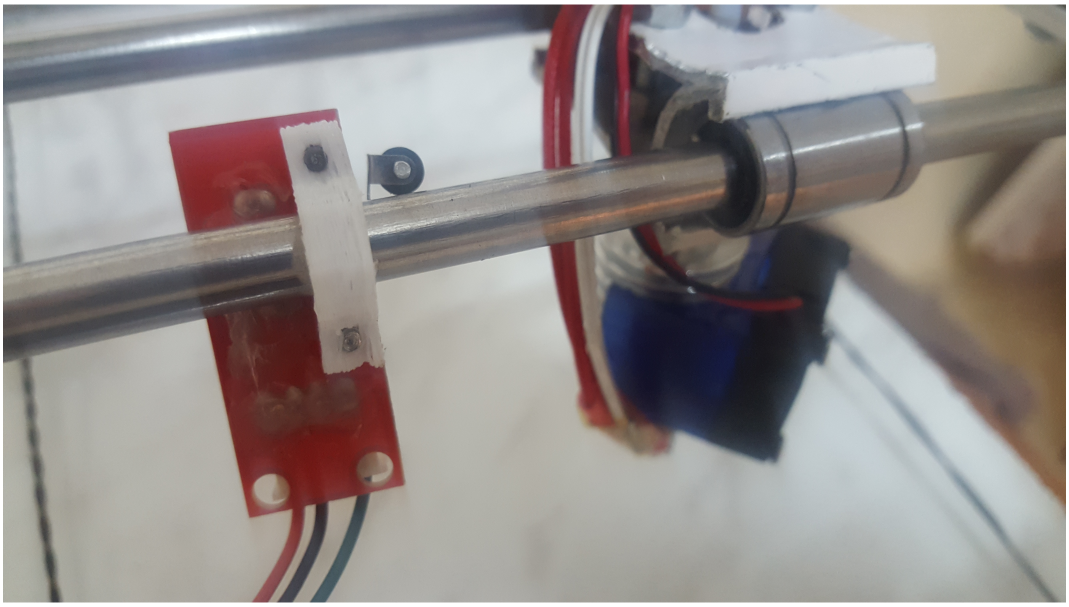

Figure 4.48: after using the 3D printed end-stop holder

- **Remark:** notice that the side of the end-stop which is in contact with the metallic rod, must be covered with some insulator to prevent short circuit.

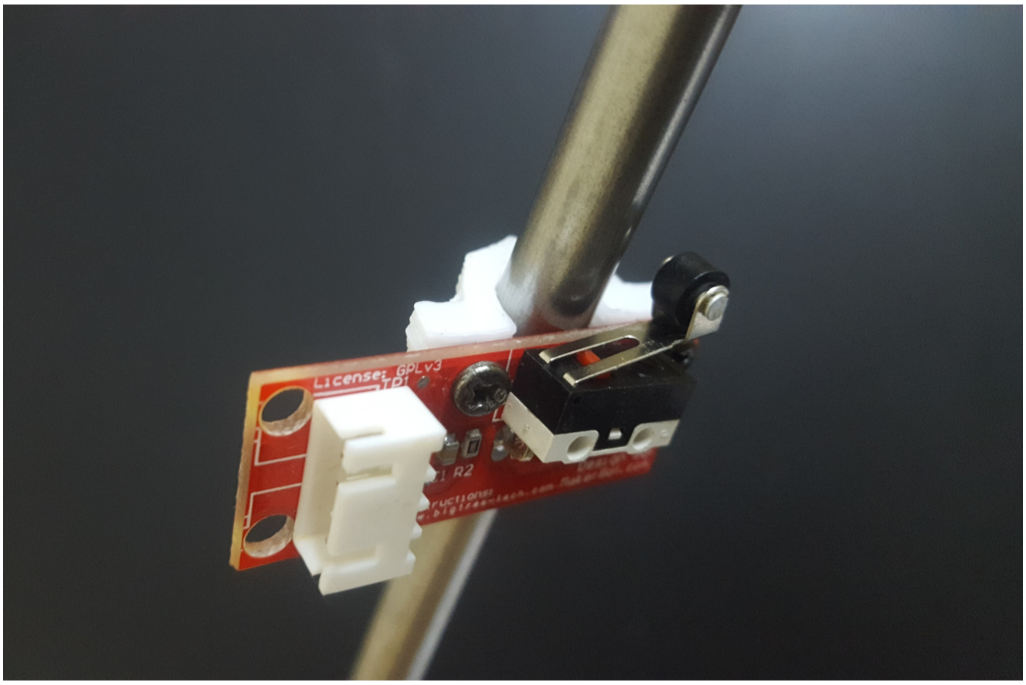

Figure 4.49: utilizing the 3D printed end-stop holder

Conclusion

In this chapter we went from the concept of the 3d printer which we have created earlier, to reality, by first going through a test build where we used a wooden frame and performed some 3d printing tests, and after that we disassembled it and used its components for a second build, we have also went in details through 3D printing processes form creating A 3D design for a mechanical piece to actually printing the object.

General Conclusion

3D printing is a revolution in the world of printing today, makes it possible to shape a product, layer after layer, by working directly from a multitude of materials, one wonders if it can come to further improvement.

In this work, we have designed and implemented a 3D printer prototype based on the technique of Fused Filament Fabrication (FFF). During the realization of the project, we really enjoyed working and we were able to acquire more ideas on the theoretical or practical level .

So, we described step by step the construction of a 3D printer, including: the study of the existing types of 3d printers, mechanical, electronics and software study. So, we set up: A mechanical system which allows movement of the printing head with two stationary stepper motors.

To showcase our work, we performed various print tests satisfactory on different geometric shapes.

Improvement to the current machine may include a sensor to monitor the level of the printing base, and more stable mechanical components .

It is worth mentioning that in order to cover all the engineering aspects of this machine, a full specialized team in electronics, mechanics, and information technology is required.

Another thing to note is that the cost of most printer parts is relatively height due to its low availability, also constructing this machine is time consuming and difficult with limited tools.

After the achievement of the realization phase of our 3D printer, and in order to highlight our project we have designed different 3D models on a design software called Designspark each of these 3D models has been printed successfully, with very satisfying result.

Different types of mechanisms may allow us to have better 3d printing results, so other mechanisms and improvements will be tested in the future.

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Abstract

3D printing is recognized as one of the greatest technological revolutions in the world today.

It represents a very important new technique for the manufacturing processes of three-dimensional solid objects.

Thus in this work we have designed and realized a 3D printer prototype using the technique of Fused Filament Fabrication (FFF).

The conception and realization of our 3D printer is divided into three parts: mechanical, electronic and software.

To achieve the mechanical construction of our model, we first designed a concept of the mechanism, the movements of these axes are guaranteed by the stepper motors, with the addition of limit switches to ensure that the printer does not exceed the border of the print area.

Then We used an Arduino MEGA board for this system to send the commands initiated from the computer and transcribed in GCODE.

This system is responsible for controlling all of the stepper motors and the temperature of the print head.

After the achievement of the realization phase of our 3D printer, and in order to highlight our project we have designed different 3D models on a design software called Designspark, each of these 3D models has been printed successfully, with a very satisfying result.