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Subject

Realization and design of a 3D printer using Arduino

By the jury composed of:

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Acknowledgment

*First of all, we thank "**Allah**" Almighty who gave us the courage, will, and strength to do this modest work. Thanks for having enlightened us on the road to success.*

*We would like to thank very warmly and our deep gratitude, in advance **the members of the jury** who will do the honor to assess this end of studies work.*

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Finally, we express our gratitude to our whole family, to all our friends, comrades, and to all who have contributed closely or by far at the culmination of this work, in particular those that we did not quote, they will always remain in our hearts.

Dedication

We dedicate this humble work :

To our parents, brothers, and sisters for your support

To all our friends whom we love and respect very much.

And to everyone we love.

ADAIKA Mohammed

DEROUICHE Mohammed

Abstract

3D printing technology is very important in all areas to distinguish it from traditional techniques. So much so that everyone and every house will be available in the next few years.

Our project is to study and investigate 3D printer and control it. This project has 4 parts: the first is a literary review about 3D printers, which includes basic knowledge about 3D printing, the second focuses on studying the technology selected in this project, and the third is to explain everything about our printer from hardware and software, and finally, in the fourth part we model and complete the project with a discussion of the results.

Keywords: 3D printer, Arduino Mega, RepRap, FDM, PLA.

Résumé

La technologie d’impression 3D est très importante dans tous les domaines pour la distinguer des techniques traditionnelles. Tant et si bien que tout le monde et chaque maison sera disponible dans les prochaines années.

Notre projet est d’étudier et d’étudier l’imprimante 3D et de la contrôler. Ce projet comprend 4 parties : la première est une revue littéraire sur les imprimantes 3D, qui comprend des connaissances de base sur l’impression 3D, la seconde se concentre sur l’étude de la technologie sélectionnée dans ce projet, la troisième est d’expliquer tout sur notre imprimante du matériel et des logiciels, et enfin dans la quatrième partie nous modélisons et complétons le projet avec une discussion des résultats.

Mots clés: 3D printer, Arduino Mega, RepRap, FDM, PLA.

ملخص

تكتسي تقنية الطباعة ثلاثية الأبعاد أهمية بالغة جدا في جميع المجالات لتميزها على التقنيات التقليدية. لدرجة أنها ستتوفر للجميع و في كل منزل في السنوات القليلة القادمة.

مشروعنا هو دراسة و تحقيق طابعة ثلاثية الأبعاد والتحكم فيها. يحتوي هذا المشروع على 4 أجزاء: الأول عبارة عن مراجعة أدبية حول الطابعات ثلاثية الأبعاد ، والتي تتضمن المعرفة الأساسية حول الطباعة ثلاثية الأبعاد ، والثاني يركز على دراسة التكنولوجيا المختارة في هذا المشروع ، والثالث هو شرح كل ما يتعلق بالطابعة لدينا من الأجهزة والبرمجيات، وأخيرًا في الجزء الرابع نقوم بنمذجة وإنجاز المشروع مع مناقشة النتائج.

الكلمات الدالة: 3D printer, Arduino Mega, RepRap, FDM, PLA.

Table of Contents

List of Figure

Chapter I: Introduction To 3D Printing

Chapter II: Study Of FDM Printers

Chapter III: Components Of FDM 3D Printer

Chapter IV: Realization Of The 3D Printer

List of Table

Notations and Abbreviations

AM : Additive manufacturing

CAD : Computer-Aided Design

CAM : Computer-Aided Manufacturing

CNC : Computer Numerical Control

RepRap : Replicating Rapid Prototype

3D : Three dimensions

X : X axis

Y : Y axis

Z : Z axis

3DP : Three Dimensional Printing

FDM : Fused Deposition Modeling

FFF : Fused Filament Fabrication

DLP : Direct Light Processing

LOM : Laminated Object Manufacturing

SLA : Stereolithography Apparatus

SLS : Selective Laser Sintering

STL : Stereolithographic

PLA : Polylactic Acid

ABS : Acrylonitrile butadiene styrene

IDE : Integrate Development Environment

USB : Universal Serial Bus

NEMA : National Electrical Manufacturers Association

LCD : Liquid Crystal display

MOSFET : Metal Oxide Semiconductor Field Effect Transistor

G-Code : General Code

SCARA : Selective Compliance Assembly Robotic Arm

PVA : Polyvinyl alcohol

RAMPS : RepRap arduino mega pololu shield

SD Card : Secure Digital Card

OBJ : Wavefront Object

DC : direct curent

General Introduction

In recent years, 3D printing has sparked a growing interest, both among manufacturers, and among technology enthusiasts and academics.

Currently, it is possible to manufacture equipment and objects of all kinds in a variety of materials, any professional or novice can create a digital representation of these models, or simply download their 3D representation files online. Then transfer this digital file to the 3D printer.

Many users even design and manufacture the printer themselves, Especially with having programmable electronic boards like Arduino and controlling any system or machine-like 3d printer.

3d printer uses data processing technology consisting of alphanumeric codes (G symbol) that represent the engineering and technological instructions needed to control the movement of three axes for our printer and many other things.

To achieve the set goals, we built this thesis as follows:

- ❖ In the first chapter, we will provide information about 3d printers in general, we started with the different stages of development of Additive Manufacturing (AM) as part of the history, then the areas of their use and the most important technologies with the choice of technology for this project.
- ❖ In the second chapter, we will present a general study of the technology used in our project and its mechanism of action with the most important materials.
- ❖ In the third chapter, a comprehensive explanation of the hardware and software that were used and relied upon in the manufacture of our printer will be presented.
- ❖ In the fourth chapter, we will design and realize our printer with a discussion of the results and the most important thing is what we can develop in the future so that we get excellent results.

Chapter I: Introduction To 3D Printing

I.1. Introduction

This chapter presents a general study of 3D printing technology, including an overview of the different techniques and processes used in it, and citing their advantages and disadvantages.

Then, we will focus our study on one of these techniques, in particular (name the technique) which is currently the most used by an overwhelming majority of 3D printers available on the market.

I.2. Définition of 3D printing

Until recently, all objects were made using three main techniques: by gradually removing the material until the piece was formed (sculpture, cutting, milling, drilling, etc.), by combining several materials (weaving, gluing, etc.) or by deforming the master to give it the desired shape (molding, folding, etc). The manufacture of an object generally combined these three processes, which required the use of many tools and the use of different materials [1].

Nowadays and with 3D printing, this production is different since the part is created in a single pass, layer after layer, at the average rate of one to two centimeters in height per hour [2].

3D printing or additive manufacturing is a new rapid prototyping technology and it is easy to manufacture a part or model with precision, for example, the production of a spare part in the space field, or the manufacture of organs in the biomedical field, etc. is the creation of a three-dimensional object from a digital model. We use materials such as plastic, metal, concrete, etc [3].

I.3. The evolution of 3D printers

3D printing technology is evolving every day, but let's take a moment to look at where it all began.

3D printing has been around for about 34 years. Back then, there was very little use of 3D printers in the industry due to their high costs. Today, the sale of such machines around the world is experiencing a significant development: a 3.47-fold increase in printer sales in two years: from 80 thousand printers in 2013 to 278 thousand printers in 2015. This huge demand has made the cost very competitive, and therefore reduced to a big limit [4].

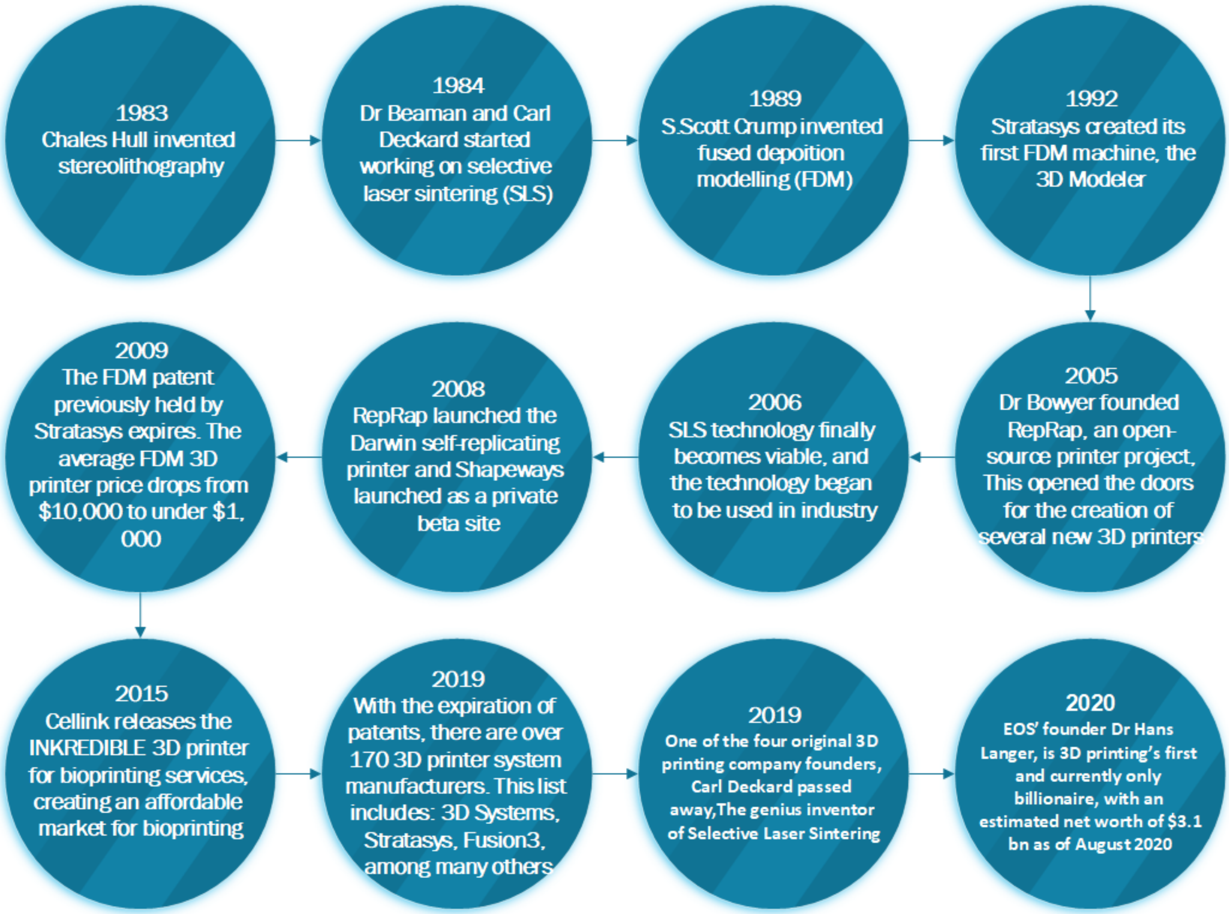


Figure I.1: A literature review on the history of 3D printing [5-6]

I.4. Advantages of additive manufacturing

Additive Manufacturing (AM) integrates three fundamental notions which are time, cost, and complexity of shapes:

- **The complexity of shapes:** 3D printing makes it possible to produce extremely complex shapes compared to other processes such as machining which depend on tools (with sometimes unattainable angles).
- **Cost:** This technology does not require tools and consumes a volume of material almost equal to the volume of the part. The ease of reproducing a part makes it possible to explore different variations of the product.
- **Time:** The objective of AM is to reduce the development time of a product by manufacturing models quickly.

Unlike digital machining (a) which sculpts a block of material by removing material, additive manufacturing (b) produces parts by adding material without generating waste **(Figure I.2).**

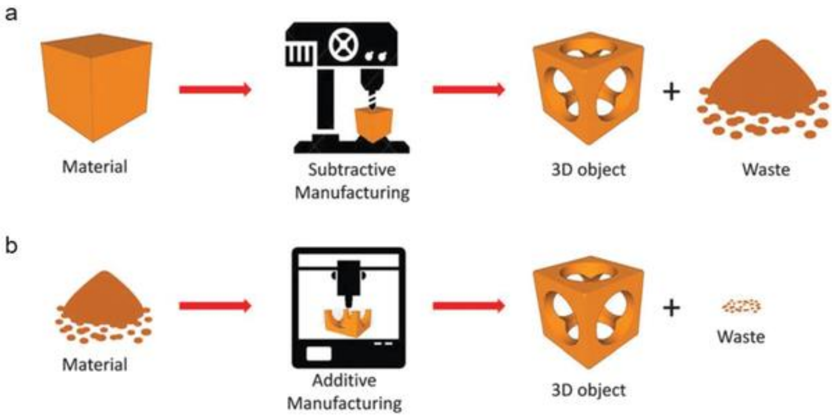
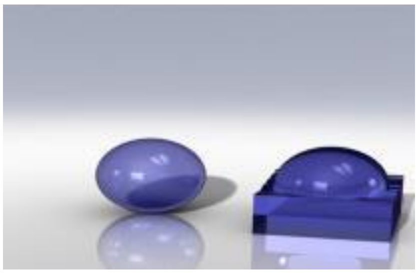


Figure I.2: Comparison between the two manufacturing methods: (a) subtractive manufacturing and (b) additive manufacturing

I.5. The difference between subtractive and additive manufacturing

Table 1- The Different between Subtractive and Additive manufacturing

SUBTRACTIVE MANUFACTURING	ADDITIVE MANUFACTURING
It is also called as machining process	It is also called 3D printing.
Take a block of material and carve it out	Take a block of material and melt it out
Generate CNC program	Software cura the 3D model into thin slices
The machine away unwanted material	The machine builds it layer by layer
If possible, recycle waste	No waste produce
Less efficient	More Efficient
Fig. Shows about this 	Fig. Shows about this 

I.6. Applications of 3D printing

3D printing is a technology with great potential. It has an active role in various industrial sectors, in particular: mechanical structures, aerospace, automobiles, and medicine, ...

Of course, prototyping is still the largest application of 3D printing that can facilitate the engineering process.

I.6.1. The aerospace sectors

Because production volumes in the aerospace industry are generally large (more than 70,000 parts per year) 3D printing has predominantly been used in the past as a prototyping solution rather than the manufacturing of end parts. Improvements in the size of industrial printers, the speed they can print at, and the available materials mean that 3D printing is now a viable option for many medium-sized production runs, particularly for high-end interior build-outs [7].

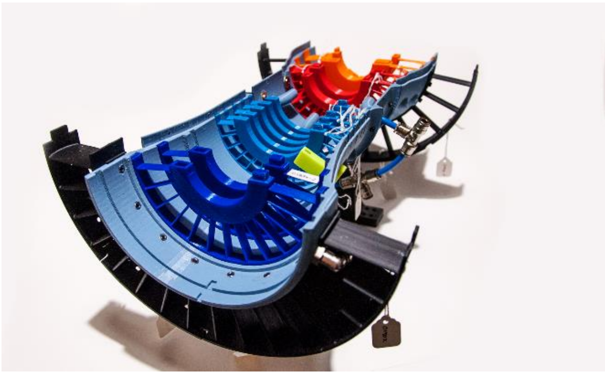


Figure I.3: A model of a jet engine for educational purposes [7]

I.6.2. The medical field

More and more doctors, dentists, and surgeons are demanding tools that help them to do their work more accurately and gently, to make their procedures less and less invasive.

Particularly in the orthopedic sector, given the constant increase in injuries due to the progressive aging of the population and broader reach of various sporting activities, Additive Manufacturing is at its best, manufacturing plates, screws, and other anatomical elements required to restore natural movement in the shortest possible time.

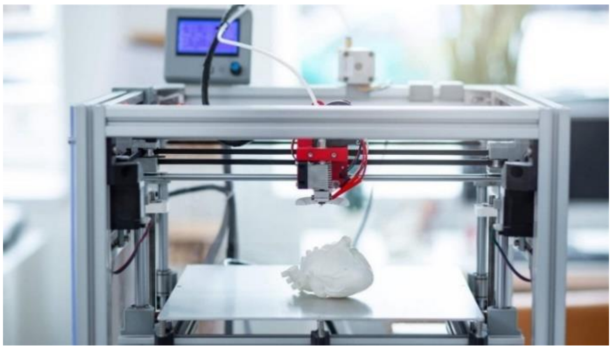


Figure I.4: 3D printer model of the human heart

I.6.3. Automotive industry

For the past few decades, 3D printing in the automotive industry was primarily used by carmakers to create automotive prototypes to check their form and fit. The first technology for building parts was selective laser sintering or binder jetting. This allowed automakers to create aesthetically pleasant parts, but they were weak and could not be used long.

According to engineering.com, today there are more robust technologies for automotive 3D printing, such as fused filament fabrication (FFF), which can be used not only for the production of prototypes but also for end-use parts [8].

Figure I.5: Printing hubcaps on a VW Microbus using the SLA 3D printing process [9]

I.6.4. Jewelry

It's important to note that when we talk about jewelry 3D printing, we don't mean directly printing jewelry in precious metals. Although this is possible -and the technology to do so is advancing rapidly- most jewelers don't use 3D printers this way, as the tech is not quite accessible in terms of price.

Instead, jewelers use 3D printers to print out master or wax models and patterns to use in combination with traditional lost wax casting. The lost wax method, if you're not familiar, is where a wax model is encased in a plaster-like medium that hardens and is then heated so the wax model melts away leaving a mold that's then filled with molten precious metal.

So instead of hand carving wax the traditional way, jewelers today 3D print in wax. A 3D printer makes it possible to create a finely detailed, master wax model [10].

Figure I.6: Various designs of jewelry printed with technology SLA [11]

I.6.5. Mechanical design

Mechanical designers are engaging with 3D printing in a myriad of different ways to explore form and function in ways previously impossible. Whether purely to find new original expressions or to learn from old masters this is a highly charged sector that is increasingly finding new ways of working with 3D printing and introducing the results to the world [12].

Figure I.7: 3D Printing Mechanical Parts [13]

I.6.6. 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 several organizations on this front, most notably Loughborough University, Contour Crafting, and Universe Architecture [12].

Figure I.8: Printed Architecture Model [14]

I.6.7. Building and construction

A construction 3D printer is a machine that can build homes by depositing a material (for example, concrete) layer by layer that is pushed through a nozzle in layers to 3D print buildings.

3D printing of concrete in the construction industry helps save time, effort, and materials compared to traditional construction methods. However, it is important to note that 3D printers are not yet capable of creating a fully functional home [15].

Figure I.9: 3D printing for the home

I.7. The different processes used in 3D printing

All 3D printers do not use the same technology. There are numerous means to print the layers to form the finished product. Some techniques liquefy the material or simply soften it to make the layers whereas others use high-powered UV laser to cure photoreactive resin and "print" the object.

Some of the 3D printing technologies that are most broadly utilized these days are: [16]

1) Stereolithography (SLA)
2) Digital Light Processing (DLP)
3) Fused deposition modeling (FDM)
4) Selective Laser Sintering (SLS)
5) Laminated object manufacturing (LOM)

Since there are different 3D printing technologies, the type to be used depends mostly on the kind of object to be made. Each of them has its claimed benefits and downsides. The next section explains each of the different processes in detail and gives examples of products that can be produced by each of them.

I.7.1. Stereolithography (SLA)

Stereolithography (SLA) is widely recognized as the first 3D printing process; it was certainly the first to be commercialized. SLA is a laser-based process that works with photopolymer resins, that react with the laser and cure to form a solid in a very precise way to produce very accurate parts.

It is a complex process but simply put, the photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .STL file), whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z-axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal.

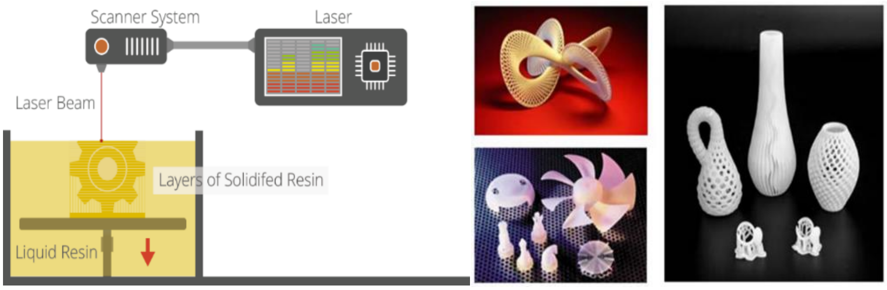


Figure I.10: Stereolithography 3D printing [17], Objects produced by SLA [16]

Because of the nature of the SLA process, it requires support structures for some parts, specifically those with overhangs or undercuts. These structures need to be manually removed.

In terms of other post-processing steps, many objects 3D printed using SLA need to be cleaned and cured. Curing involves subjecting the part to intense light in an oven-like machine to fully harden the resin. Stereolithography is generally accepted as being one of the most accurate 3D printing processes with excellent surface finish. However, limiting factors include the post-processing steps required and the stability of the materials over time, which can become more brittle.

I.7.2. The Digital Light Processing (DLP)

DLP or -digital light processing- is a similar process to stereolithography in that it is a 3D printing process that works with photopolymers. The major diffrefence is the light source. DLP uses a more conventional light source, such as an arc lamp, with a liquid crystal display panel or a deformable mirror device (DMD), which is applied to the entire surface of the vat of photopolymer resin in a single pass, generally making it faster than SLA.

Also, like SLA, DLP produces highly accurate parts with excellent resolution, but its similarities also include the same requirements for support structures and post-curing. However, one advantage of DLP over SLA is that only a shallow vat of resin is required to facilitate the process, which generally results in less waste and lower running costs.

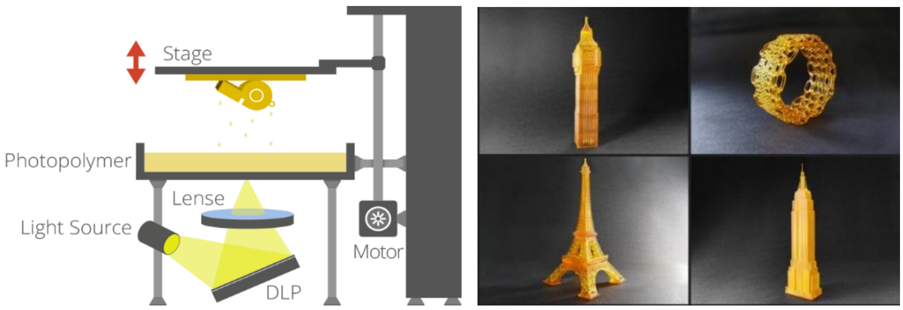


Figure I.11: Operation of the DLP Projector [17], Prototypes printed by DLP [16]

I.7.3. Extrusion / Fused Deposition Modeling

3D printing utilizing the extrusion of thermoplastic material is easily the most common and recognizable 3D printer process. The most popular name for the process is Fused Deposition Modeling (FDM).

The process works by melting plastic filament that is deposited, via a heated extruder, a layer at a time, onto a build platform according to the 3D data supplied to the printer. Each layer hardens as it is deposited and bonds to the previous layer. The FDM/FFF processes require support structures for any applications with overhanging geometries [18].

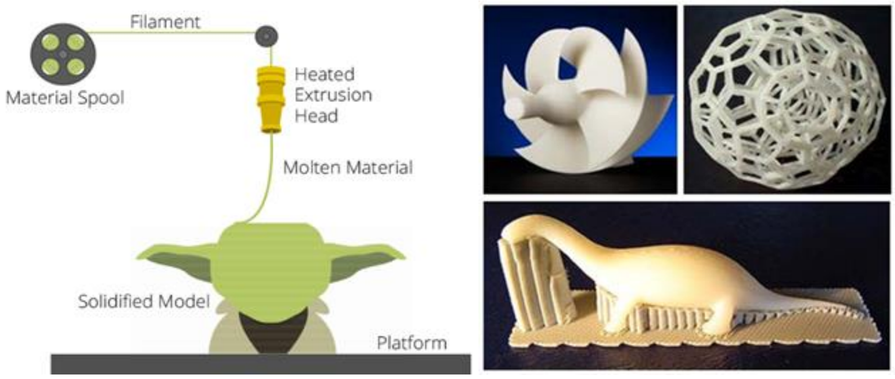


Figure I.12: Fused Deposition Modeling 3D printing [17], Typical objects printed by FDM [16]

I.7.4. Selective Laser Sintering (SLS)

Another technology used by today’s 3D printer is the Selective Laser Sintering (SLS). During this process, tiny particles of plastic, ceramics, or glass are joined by heat from a high-powered laser beam to form a solid.

The laser is traced across a powder bed according to the data file. The powder inside the powder bed is tightly compressed. The laser moves in the X and Y directions. The laser then hits the surface of the powdered material; it sinters the particles to each other to give form to a solid. When one layer is completed, the powder bed lowers in the Z direction, and the leveling drum (roller) smoothest the powder over the surface of the bed. The laser then continues to trace and form the design required. The process repeats itself until the whole object is printed. The object is then left to be cooled down.

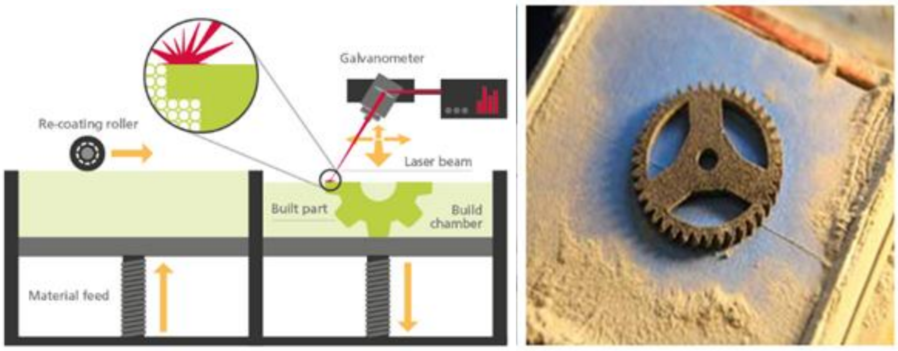


Figure I.13: Basic setup of SLS, Parts printed by SLS [16]

The build chamber needs to be completely sealed because it is necessary to maintain the temperature during the process to be the same as the melting point of the powdered material. The powder bed is removed from the machine when the process is completed, and the excess powder is easily taken out of the printed object.

One of the major advantages of SLS is that it does not require any structural support for complex parts as needed in both Stereolithography and Fused Deposition Modelling. Because the part lies on a bed of powdered material, no supports are necessary.

This advantage itself helps save material and reduces production costs. There is also not much need for post-processing. Moreover, SLS is capable of printing geometries that cannot be done using other 3D printed methods. Using SLS, parts with complex interior components can also be printed and there is no problem of removing supports and damaging the part. As a result, time is saved on assembly. Parts printed by SLS are usually very durable and robust. This technology now rivals those produced in traditional methods like injection molding and is already used in many end-use applications like automotive and aerospace.

I.7.5. Laminated object manufacturing (LOM)

LOM can be regarded as a hybrid technology situated between additive and subtractive manufacturing. The building procedure is based on sequential lamination of 2D sheets, each of which is then cut according to the object contours [19].

It is more popular in the production of customized objects than for personal or industrial use. The reason is the fact that at the low cost of raw materials LOM devices are much more expensive than FDM printers [20].

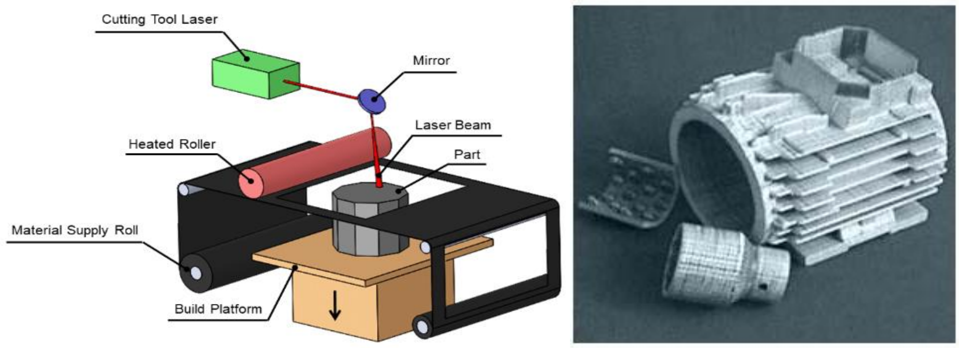


Figure I.14: Laminated Object Manufacturing process [21], Prototypes printed by LOM [16]

I.7.6. Comparison of different types of 3D printing technologies

Table 2- Comparison of different types of 3D printing technologies [16}

	SLA	FDM	SLS	LOM	DLP
Applications	- Excellent for form testing - The best process for water-resistant material	- Suitable for prototypes - Home use applications	- Ideal for functional parts with various application - Suitable for a complex shape object - Heat and chemical resistant	- Ideal for nonfunctional prototypes	- Similar to SLA
Overall Accuracy	- The most accurate printing process	- Accurate and reliable process	- Not very accurate	- Slightly less dimensional accuracy	- High Accuracy
Material Options	- ABS - Semi-flexible materials	- Thermoplastic materials	- Nylon - Glass-Filled Nylon	- Paper - Plastic - Metal	- Similar to SLA
Finish Options	- Excellent surface finish	- Standard Finish	- Standard Finish	- Wood-like characteristics and can be treated similarly	- Good finish - High resolution
Post Processing Requirement	- Requires post-processing to remove the support structure	- Requires post-processing to remove the support structure	- Does not require the support structure, less post-processing requires	- Polishing - Painting	- Requires Post processing

I.7.7. Conclusion and Discussion

The type of technology to be used depends mostly on the object to be manufactured. A comparison was carried out to show which method is the best fit for a particular job.

- **Stereolithography** is the most popular 3D printing technology. It is widely used nowadays because it provides accuracy along with an excellent surface finish. It also allows the printing of objects using a variety of materials. However, it can be expensive and is used mostly by industries for making prototypes. Digital Light Processing is quite similar to Stereolithography. The main difference between these two technologies is their type of light source [16].
- **Fused Deposition Modeling** is a less expensive process compared to all other 3D printing methods. This makes it suitable for home use applications. The level of accuracy and surface finish it provides are worth the manufacturing cost. However, the materials that FDM supports are limited mostly to thermoplastics [16].
- **Selected Laser Sintering** is a good choice for building objects with complex shapes and geometries. It does not require additional support like other 3D printing technologies and does not need much post-processing. Nevertheless, the final object might not be very accurate and the surface finish is not so good and High laser energy can degrade thermolabile Pas [16].
- **Laminated Object Manufacturing** is an ideal choice for the non-functional prototype. It does not provide a good accuracy level and surface finish. It also requires much post-processing. The material mostly used for this process is paper.

I.8. Choice of 3D Printer technology

The analysis of the current market of 3D printers from a technological point of view, has us pushed to opt, for the technique of 3D printing by Fused Deposition Modeling, since it allows, on the one hand, to meet the need of our project (availability, feasibility) and on the other hand, On the other hand, it ensures the necessary precision to make objects for educational use.

In addition to the reasons mentioned earlier, Fusion Filament Fabrication is the most used 3D printing technology nowadays.

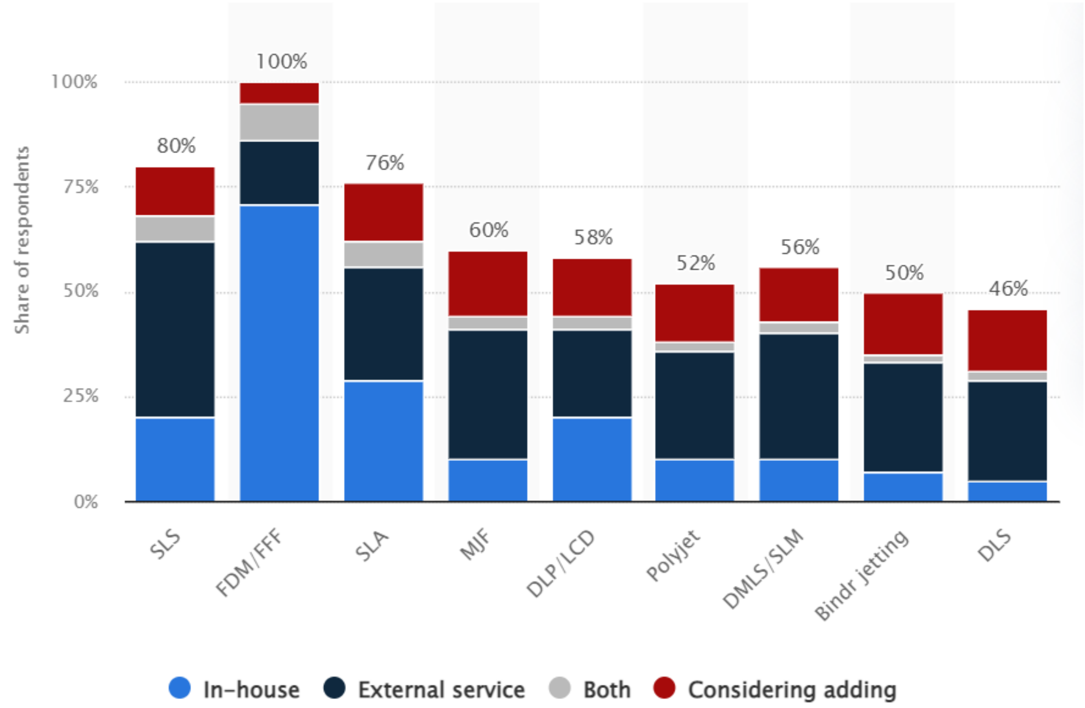


Figure I.15: Worldwide most used 3D printing technologies, as of July 2018 [22]

I.9. Conclusion

In this chapter, we saw that the 3D printer industry continues to grow. The goal of professionals is to be able to install a printer in each home, especially for everyday needs. According to experts, by 2030, people will use 3D printers at home to print everyday objects.

After understanding how the different technologies of 3D printers work in a variety of fields, we will begin to study the technique selected for this project, which is the Fusion Filament Fabrication (FFF) technology by identifying the mechanisms used in it.

Chapter II: Study Of FDM Printers

II.1. Introduction

In this chapter, we will see the mechanics of 3D printing with the selection of the appropriate mechanism for our project to be achieved, and we will also see how this printing works and some details about its most important components with a brief definition of the materials used in printing.

II.2. Différence between FDM and FFF

The only difference in name between "fused filament fabrication" and "fused deposition modeling" is due to a legal issue. FDM is a registered trademark of the 3D printer manufacturer: Stratasys. Scott Crump, founder of Stratasys, and inventor of fused deposition modeling trademarked the term in 1991 shortly after he developed the 3D printing process. This means that only Stratasys products can use the phrase "fused deposition modeling" in their product names and marketing.

This created some problems for other companies interested in developing similar technology. To solve this problem, the term "fused filament fabrication" has become popular. This allowed people and companies to discuss and develop 3D printing technologies without fear of litigation for use of the FDM trademark.

Previously, 3D printer manufacturers might have had problems if they advertised their products as using embedded deposition modeling techniques without realizing that the term was a trademark. But the patent expired in 2009 [23-24].

II.3. Fused filament fabrication 3D printers

The Fused Deposition Modeling (FDM) process constructs three-dimensional objects directly from 3D CAD data. but the print head must be able to extrude a material on a two-dimensional plane as a layer, and also on top of this layer, so the movement on the three axes X, Y, and Z In the following we will talk about the most important mechanisms used in the technology of fused filament fabrication.

II.4. 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.

In reality, there are many aspects that one could consider to differentiate (FFF/FDM) printers. That said, perhaps the two most important features are the operational coordinate system and the mechanical nature.

On the coordinate system side of things, six of our seven FDM printers, polar 3D printers being the exception, use Cartesian coordinates. This means that delta, CoreXY, H-bot, SCARA, and belt printers technically fall under the Cartesian classification. However, most of them aren't referred to as "Cartesian" because they have more specific names, which often have to do with their mechanics [25].

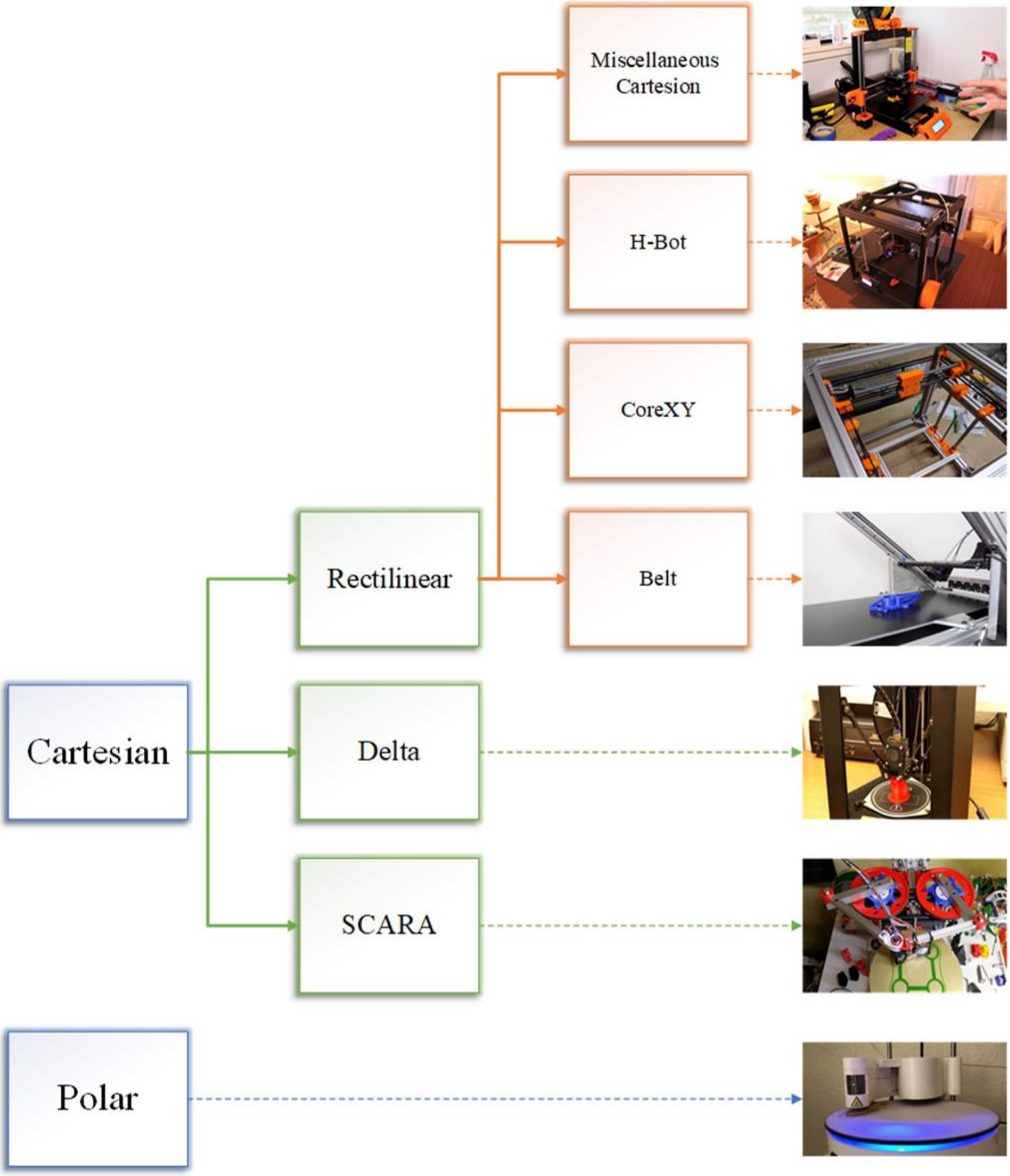


Figure II.1: The Types of FDM 3D Printers

And as we saw in the previous diagram, it can be divided into 2 basic types:

II.4.1. Cartesian FDM printers

Cartesian printers are the most common FFF/FDM printers on the market. The technology uses three axes-X, Y, and Z (Cartesian coordinate system) to determine the movements of mechanical parts: the print head and the bed move according to the coordinates [26].

It can be divided into 3 basic types:

II.4.1.1. Rectilinear

Rectangular printers are "modular" 3D printers, with right-angle frames and linear axes. These printers move components linearly along the X, Y, and Z axes to place the print within a 3D space. The print head generally moves along an X or Y bridge, which in turn moves along the Z-axis, although other changes in movement can occur, depending on the printer. It consists of several types: [25]

1. Miscellaneous Cartesian
2. H-Bot
3. CoreXY
4. Belt

II.4.1.2. Delta

Delta printers are different from Cartesian ones both externally and in the work process. The main difference lies in the way the extruder moves about the print bed [26].

II.4.1.3. SCARA (Selective Compliance Assembly Robotic Arm)

Robotic arms are best known for assembling components on industrial production lines, especially in large automotive factories. They are little used to extrude filament. 3D printing via these machines is still at the development stage, only a few companies use this technology for the construction of houses for example [27].

II.4.2. Polar FDM printers

This new and interesting polar design is represented on the market by a company named Polar. It means the positioning is determined by radius and angle instead of commonly used XYZ-axes [26].

II.5. Flowchart of 3D printer operation

The corresponding figure shows the stages of operating a 3D printer. The process begins with modeling and preparing the desired design, which will be converted to .stl format before slicing for 3D printing. The 3D model will then be converted to G-code in the slicer software. The pattern is cut into layers, and printing parameters such as layer thickness, printing speed, and filling density are adjusted during the cutting process. The G-code will then be uploaded or transferred to the 3D printer to start manufacturing the design [28].

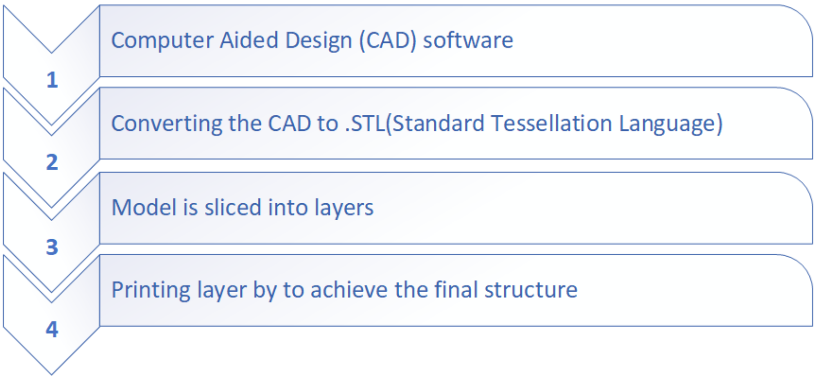


Figure II.2: The flowchart of the 3D printing process

II.6. Diagram of a 3D Printer

Any FDM printer will have the components shown in **Figure II.3**:

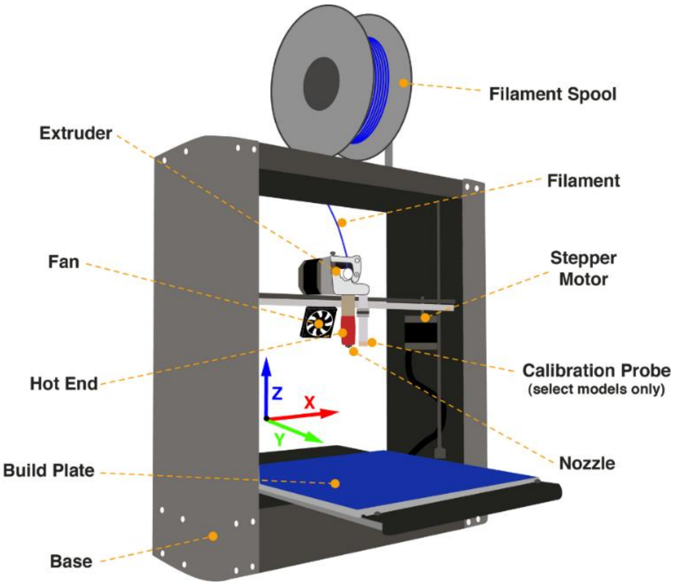


Figure II.3: Diagram of a 3D Printer

Here's a basic description of what the parts of an FDM printer do:

- The build plate (or print bed) is a level, flat area where the 3D print starts.
- A filament spool holds the plastic that will be melted.
- Thin filament, usually a type of thermoplastic, is wrapped around a filament spool and is the raw material the 3D printer uses to make objects. Consumer printers print with filament that is one of two diameters: 1.75mm or 3mm.
- The extruder is the name for the assembly that grabs the filament and pushes it through a heating block.
- Stepper motors drive the belts and extruder up/down, left/ right, and forward/back.
- The chassis is the frame of the 3D printer, which could be made from metal, plywood, etc.
- The hot end is the part of the extruder that heats the filament to just the right temperature based on that material, with a nozzle at the bottom to allow the molten filament to flow through.
- A fan controls the temperature at which each layer cools, making the depositing and bonding of the layers more successful.

II.7. Printing materials for the FDM 3D printer

The materials used by rapid prototyping by wire deposition (FDM/FFF) are several, but low-cost printers mainly use thermoplastics: the most common are ABS and PLA.

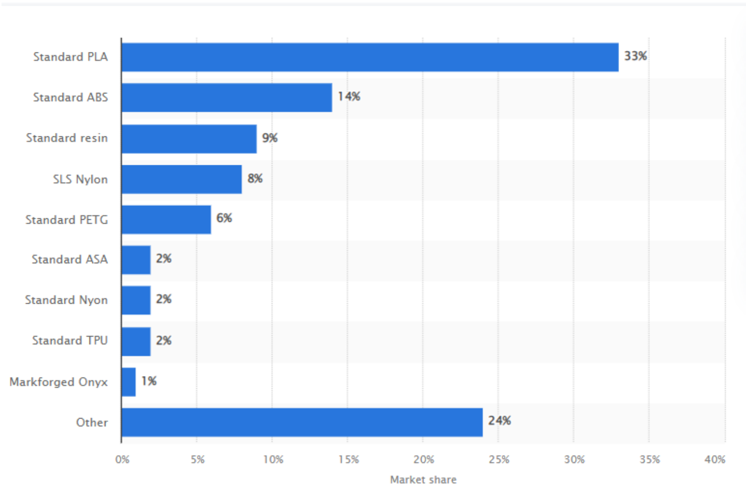


Figure II.4: Worldwide most used 3D printing materials, as of July 2018 [29]

II.7.1. PLA (Polylactic Acid)

Polylactic acid, also known as PLA, is a thermoplastic monomer derived from renewable, organic sources such as corn starch or sugar cane. Using biomass resources makes PLA production different from most plastics, which are produced using fossil fuels through the distillation and polymerization of petroleum [30].

Figure II.5: 3D printed parts with PLA [31]

II.7.2. ABS (Acrylonitrile Butadiene Styrene)

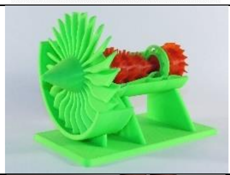
ABS polymers are a unique family of technical polymers. Its name is indicated by the initials of the three monomers that make up it: acrylonitrile which provides thermal resistance to aging; Butadiene, which contributes to maintaining properties at low temperatures, hardness, and impact resistance, and styrene, which gives rigidity and ease of forming in general, ABS is not resistant to weathering. If ABS furniture is exposed outdoors, its color may vary and fade, and it melts at a temperature of about 200 degrees. It is available in several colors, and it is also commonly used to manufacture everyday objects, particularly toys.

Figure II.6: 3D printed parts from ABS [31]

II.7.3. Common FFF filament

Each type of filament has certain heating properties and requirements for building platforms. Table 5 lists the more common filaments available, along with their abbreviations and brief descriptions. The melting point (in this case, the temperature that the filament becomes soft enough to extrude) is listed as degrees Celsius [32].

Table 3- Filament Types [32-33]

Type	Abréviation	Melting Point (Celsius)	Description	Illustrative image
Polycarbonate	PC	155	- Is ideal for complex 3D prints	
Aliphatic polyamide	Naylon	220	- Low friction - Somewhat pliable	
Acrylonitrile butadiene styrene	ABS	215	- Flexible - Easy to modify (carve, sand, etc)	
Polyvinyl alcohol	PVA	180	- Dissolves in cold water - Used for support material	
Polylactic acid	PLA	160	- Derived from plants and biodegradable	

II.8. Process Paramètres

The FDM process has several process parameters, and they have a significant impact on production efficiency and part characteristics.

Table 4- Fused filament fabrication (FFF) process parameters [34-35]

Category	Parameter	Brief Description
Slicing parameters	Layer thickness/height	The thickness of each deposited layer in the build platform
	Print speed	The distance an extruder goes per unit time during the print process

	Infill density	The percentage of the volume of the internal structure to be filled with filament material
	Infill pattern	Some common infill patterns are hexagonal, diamond, or linear
	Air gaps	the gap between two adjacent rasters on a deposited layer. The air gap is called negative when two adjacent layers are overlapped
Temperature Conditions	Extrusion temperature	The temperature at which the filament is heated in a liquefier during the FFF process
	Bed/platform temperature	The temperature of the printing bed or build platform

II.9. Stepper Motors

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed number of degrees. This feature is obtained thanks to the internal structure of the motor and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications [39].

II.9.1. Working Principles

Like all electric motors, stepper motors have a stationary part (the stator) and a moving part (the rotor). On the stator, there are teeth on which coils are wired, while the rotor is either a permanent magnet or a variable reluctance iron core. **Figure II.7** shows a drawing representing the section of the motor is shown, where the rotor is a variable-reluctance iron core [36].

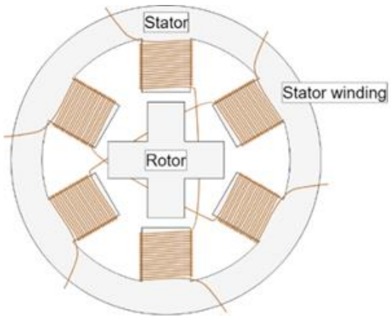


Figure II.7: Cross-Section of a Stepper Motor [39]

II.9.2. Types and Construction

The performance of a stepper motor - both in terms of resolution (or step size), speed, and torque - is influenced by construction details, which at the same time may also affect how the motor can be controlled. Not all stepper motors have the same internal structure (or construction), as there are different rotor and stator configurations [36].

Engine design There are 3 technologies:

- permanent magnet motor
- Hybrid motor combining magnet and variable reluctance
- Variable reluctance motor

II.9.2.1. Permanent magnet motor

The rotor is a permanent magnet that aligns with the magnetic field generated by the stator circuit. This solution guarantees a good torque and also a detent torque. This means the motor will resist, even if not very strongly, a change of position regardless of whether a coil is energized. The drawbacks of this solution are that it has a lower speed (a low number of steps per revolution) and a lower resolution compared to the other types. **Figure II.8** shows a representation of a section of a permanent magnet stepper motor [36].

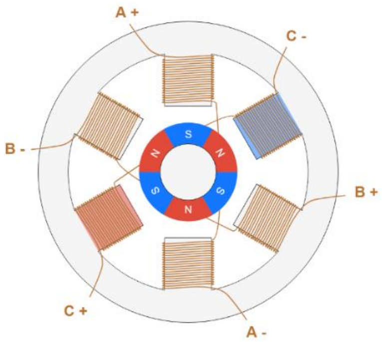


Figure II.8: Permanent Magnet Stepper Motor [36]

II.9.2.2. Hybrid motor combining magnet and variable reluctance

This kind of rotor has a specific construction and is a hybrid between the permanent magnet and variable reluctance versions. The rotor has two caps with alternating teeth and is magnetized axially. This configuration allows the motor to have the advantages of both the permanent magnet and variable reluctance versions, specifically high resolution, speed, and torque. This higher performance requires a more complex construction, and therefore a higher cost. **Figure II.9** shows a simplified example of the structure of this motor. When coil A is energized, a tooth of the N-magnetized cap aligns with the S-magnetized tooth of the stator. At the same time, due to the rotor structure, the S-magnetized tooth aligns with the N-magnetized tooth of the stator. Real motors have a more complex structure, with a higher number of teeth than the one shown in the picture, though the working principle of the stepper motor is the same. The high number of teeth allows the motor to achieve a small step size, down to 0.9° [37].

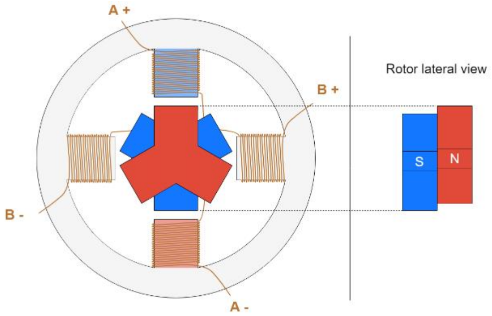


Figure II.9: Hybrid Stepper Motor [36]

II.9.2.3. Variable reluctance motors

The rotor is made of soft iron and has a different number of poles from the stator. The rotor moves so that the flux passing through it is maximum. These motors have no holding torque if no coil is energized [36].

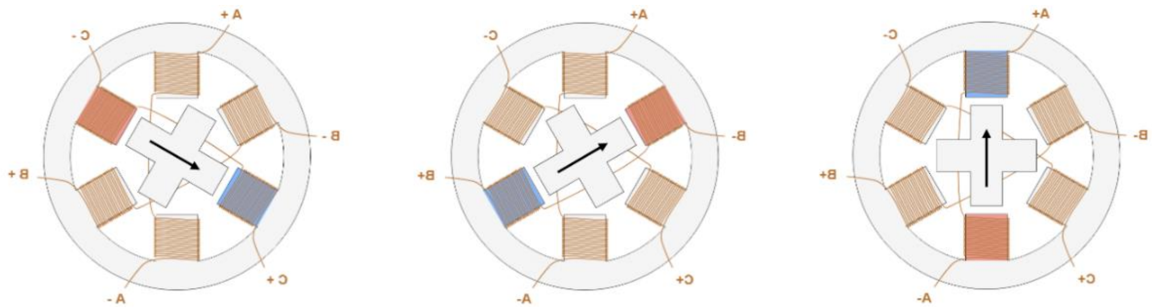


Figure II.10: Variable reluctance Stepper Motor [36]

II.9.3. Bipolar/Unipolar Motors

The windings of a bipolar motor are energized once in one direction, and once in the other direction. They create once a north pole, once a south pole hence the name bipolar. With technology progress, the advantages of unipolar are becoming less relevant, and bipolar steppers are currently the most popular.

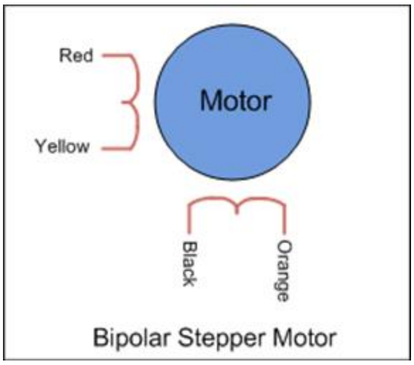


Figure II.11: Representation of a diagram of the bipolar motor [38]

The windings of a unipolar motor are always supplied in the same direction by a single voltage, hence the name unipolar.

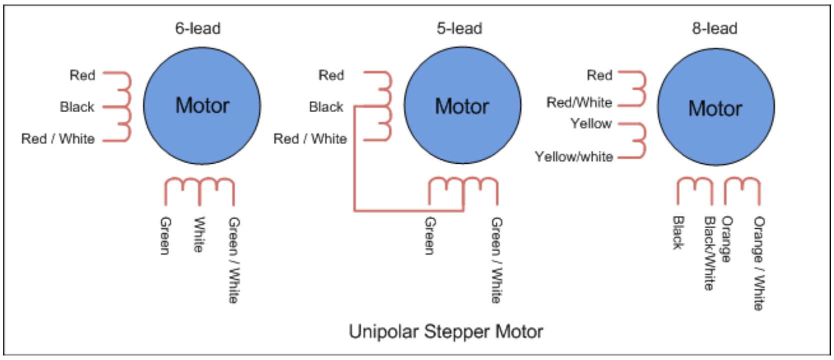


Figure II.12: Representation of a diagram of the unipolar motor [38]

II.9.4. Stepper Motor Driving Techniques

There are four different driving techniques for a stepper motor: [36]

II.9.4.1. Wave mode

In wave mode, only one phase at a time is energized. Starting from the left, the current is flowing only in phase A in the positive direction and the rotor, represented by a magnet, is aligned with the magnetic field generated by it. In the next step, it flows only in phase B in the positive direction, and the rotor spins 90° clockwise to align with the magnetic field generated by phase B. Later, phase A has energized again, but the current flows in the negative direction, and the rotor spins again by 90°. In the last step, the current flows negatively in phase B and the rotor spins again by 90°.

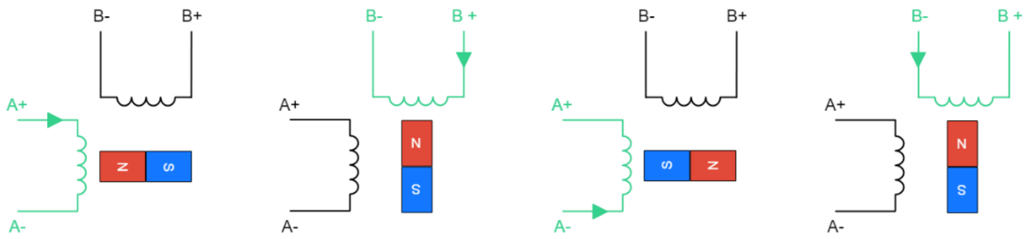


Figure II.13: Wave Mode Steps

II.9.4.2. Full-step mode

In full-step mode, two phases are always energized at the same time. the most significant difference is that with this mode, the motor can produce a higher torque since more current is flowing in the motor and a stronger magnetic field is generated.

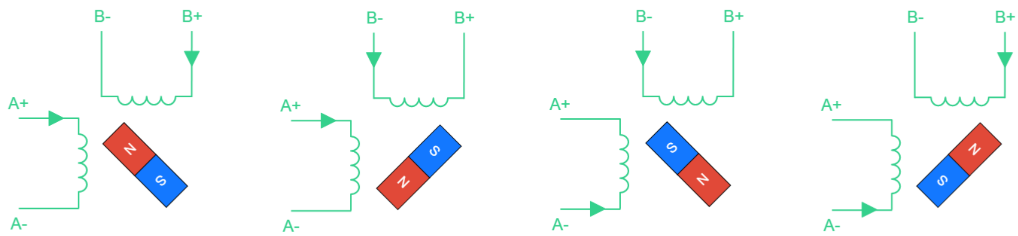


Figure II.14: Full-Step Mode Steps

II.9.4.3. Half-step mode

The half-step mode is a combination of wave and full-step modes. Using this combination allows for the step size to be reduced by half (in this case, 45° instead of 90°). The only drawback is that the torque produced by the motor is not constant, since it is higher when both phases are energized, and weaker when only one phase is energized.

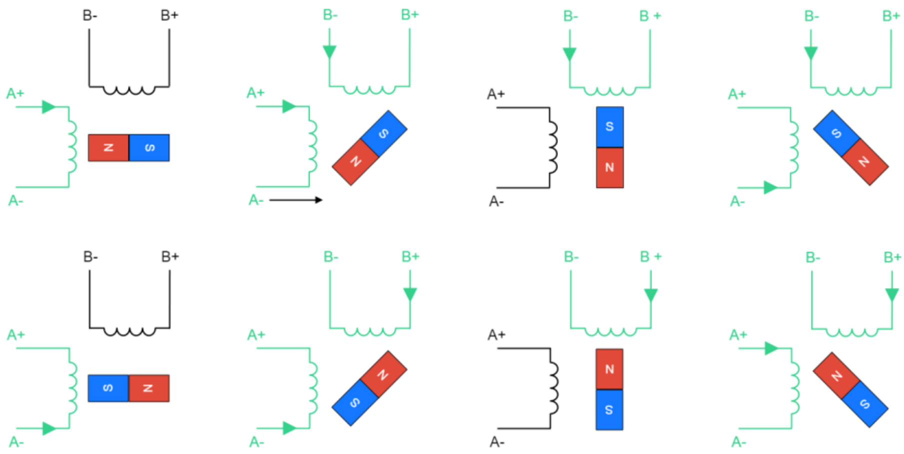


Figure II.15: Half-Step Mode Steps

II.9.4.4. Microstepping

Microstepping can be seen as a further enhancement of the half-step mode because it allows to reduce even further the step size and have a constant torque output. This is achieved by controlling the intensity of the current flowing in each phase. Using this mode requires a more complex motor driver compared to the previous solutions. If IMAX is the maximum current that can flow in a phase, starting from the left, in the first figure IA = IMAX and IB = 0. In the next step, the currents are controlled to achieve IA = 0.92 x IMAX and IB = 0.38 x IMAX, which generates a magnetic field that is rotated by 22.5° clockwise compared to the previous one. This step is repeated with different current values to reach the 45°, 67.5°, and 90° positions. This provides the ability to reduce by half the size of the step, compared to the half-step mode; but it is possible to go even further. Using microstepping helps reach very high position resolution, but this advantage comes at the cost of a more complex device to control the motor, and a smaller torque generated with each step. Indeed, the torque is proportional to the sine of the angle between the stator magnetic field and the rotor magnetic field; therefore, when the steps are smaller, the torque is smaller. This may lead to missing some steps, meaning the rotor position does not change even if the current in the stator winding has.

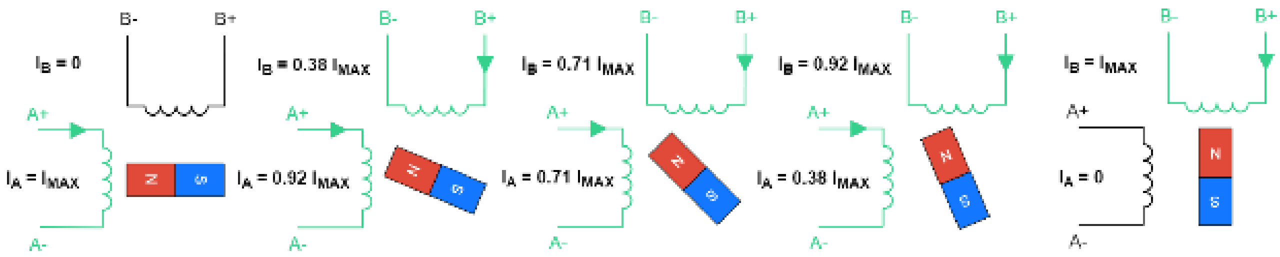


Figure II.16: Microstepping

II.9.5. Why stepper motors?

II.9.5.1. Advantages

- Stepper motors do not require a sensor to detect the motor position. Since the motor moves by performing “steps,” by simply counting these steps, you can obtain the motor position at a given time.
- In addition, stepper motor control is pretty simple. The motor does need a driver. In general, the control effort is lower compared to other motors. With microstepping, you can reach high position accuracy, up to approximately 0.007°.
- Stepper motors offer good torque at low speeds and also tend to have a long lifespan [36].

II.9.5.2. Disadvantages

- If the load torque is too high. This negatively impacts the control, since there is no way to know the real position of the motor. Using microstepping makes stepper motors even more likely to experience this issue.
- Stepper motors have low torque and become pretty noisy at high speeds.
- Harder to run than a DC motor [36].

II.10. Définition of a firmware

Firmware housed in the Arduino board of the 3D printer. He takes care of interpreting the manufacturing instructions of the 3d model (G-code) into movements taking into account the specific properties of the machine. The firmware configuration is unique for each 3D printer model, it is the link between software and hardware.

There are several firmware's, more or less similar and allowing to activate more or less functions. These include printer:

- Teacup
- Sjfw
- Marlin
- Sailfish
- Grbl

The firmware adopted for our 3D printer is the Marlin firmware.

II.10.1. Definition of marlin

Marlin is an open-source firmware for 3D printers. It was a standalone open-source project on August 12, 2011. Marlin is licensed under the GPLv3 and is free for all applications.

Marlin 2.x has added support for 32-bit boards. 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 and Re-Arm with Ramps 1.4 [39].

II.10.2. How Marlin Works

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 [39].

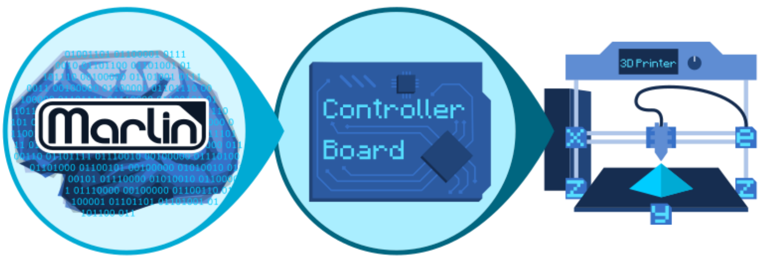


Figure II.17: Marlin firmware [39]

II.10.3. Role of marlin

Marlin firmware allows to:

- Read the G-code and execute the print.
- Manage interruptions.
- Control the acceleration and deceleration of stepper motors.
- Detect and control the temperature of the extruder and the heated bed.
- Read and write to SD card.
- Support LCD screen display.
- Calculate and plan trajectories.
- Check the ignition of the heating thermistors, and the reading of the sensor values [39].

II.10.4. Classification of firmware files

The firmware is composed of several files written in C++. Mix of .ccp files and .h headers, we can classify them according to their uses in libraries [40-41].

By classifying the files, we will find that we have (9) libraries, but we will talk about the most important library, which are:

II.10.4.1. Library configuration

File library containing all the basic configurations for printing:

✓ **"configuration.h"** which contains:

→ **Baudrate:** This is the communication speed between the computer and the printer's motherboard.

```
#define BAUDRATE 250000
//#define BAUD_RATE_GCODE     // Enable G-code M575 to set the baud rat
```

→ **Selection of the motherboard:** Among a very wide choice of shield cards, we must indicate the card used.

```
// Choose the name from boards.h that matches your setup
#ifndef MOTHERBOARD
#define MOTHERBOARD BOARD_RAMPS_14_EFB
#endif
```

→ **Number of extruders:** This parameter defines the number of extruders mounted on the printer, which can be up to 4.

```
// This defines the number of extruders
// :[0, 1, 2, 3, 4, 5, 6, 7, 8]
#define EXTRUDERS 1
```

→ **Custom Machine Name:** This is the name of printer as displayed on the LCD, if you set this to “My Delta” the LCD will display “My Delta ready” when the printer starts up.

```
//#define CUSTOM_MACHINE_NAME "3D Printer"
```

→ **Filament Diameter:** This is the “nominal” filament diameter as written on the filament spool (1.75, 2.85, and 3.0)

```
#define DEFAULT_NOMINAL_FILAMENT_DIA 1.75
```

→ **Type of temperature sensors:** from a list of temperature sensors, we will have to choose the one mounted on the extruder and on the heated bed of our printer. We use one extruder and a heated bed, so we only need to handle the 1st and 9th rows while keeping the other rows with a value of 0.

```
1.  #define TEMP_SENSOR_0 1
2.  #define TEMP_SENSOR_1 0
3.  #define TEMP_SENSOR_2 0
4.  #define TEMP_SENSOR_3 0
5.  #define TEMP_SENSOR_4 0
6.  #define TEMP_SENSOR_5 0
7.  #define TEMP_SENSOR_6 0
8.  #define TEMP_SENSOR_7 0
9.  #define TEMP_SENSOR_BED 1
10. #define TEMP_SENSOR_PROBE 0
11. #define TEMP_SENSOR_CHAMBER 0
12. #define TEMP_SENSOR_COOLER 0
13. #define TEMP_SENSOR_BOARD 0
14. #define TEMP_SENSOR_REDUNDANT 0
```

→ **Dummy thermistor:** Marlin provides two dummy sensors for testing purposes.

```
// Dummy thermistor constant temperature readings, for use with 998 and 999
#define DUMMY_THERMISTOR_998_VALUE 25
#define DUMMY_THERMISTOR_999_VALUE 100
```

→ **Maximum temperature:** for safety measures, maximum temperatures to be reached for the extruder and the heated bed must be defined. If this temperature is reached, the system cuts the power automatically.

```
// Above this temperature the heater will be switched off.
// This can protect components from overheating, but NOT from shorts and failures.
// (Use MINTEMP for thermistor short/failure protection.)
#define HEATER_0_MAXTEMP 275
#define HEATER_1_MAXTEMP 275
#define HEATER_2_MAXTEMP 275
#define HEATER_3_MAXTEMP 275
#define HEATER_4_MAXTEMP 275
#define HEATER_5_MAXTEMP 275
#define HEATER_6_MAXTEMP 275
#define HEATER_7_MAXTEMP 275
#define BED_MAXTEMP      150
```

```
#define CHAMBER_MAXTEMP  60
```

→ **Axes limits:** these parameters define the maximum length that the axes can travel from position 0, which therefore limits the volume that can be printed.

```
// The size of the printable area
#define X_BED_SIZE 160
#define Y_BED_SIZE 130
// Travel limits (mm) after homing, corresponding to endstop
positions.
#define X_MIN_POS 0
#define Y_MIN_POS 0
#define Z_MIN_POS 0
#define X_MAX_POS X_BED_SIZE
#define Y_MAX_POS Y_BED_SIZE
#define Z_MAX_POS 120
```

→ **The motor turning direction:** in these rows, we can define the motor turning direction for every motor used (this row for the x-axe motor), and to do that we need to connect all of the end stops and steppers to the Ramps board and power the printer, then connect the printer to the PC and used “Printrun”.

Printrun allow us to move the axis to any direction, so we moved the axis 10mm and confirmed if the steppers turned the right way, if not we need to change (True) value to (False) on the axis, then save the file and compile it again, and repeat this process for all motors(Y,Z,E).

```
#define INVERT_X_DIR true
```

→ **LCD enabled:** We can choose to enable LCD screen by write the LCD screen type we use and it is the RepRap Discount Full Graphic Smart Controller.

```
#define REPRAP_DISCOUNT_FULL_GRAPHIC_SMART_CONTROLLER
```

→ **Movement parameters:** These are the most important settings for the printer, as they determine how accurately the stepper axes are positioned. We also specify how many steps the motor must take to move the axle by 1 mm. For an extruder, it is the number of steps to take to remove 1 mm of filament from the extrusion head.

```
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 80, 80, 400, 98.04 }
```

The default steps is: { 80, 80, 400, 100 }

With:

- ✓ 80 for the X axes step per unit.
- ✓ 80 for the Y axes step per unit.
- ✓ 400 for the Z axes step per unit.
- ✓ 98.04 for the extruder step per unit.

Those values depend on various factors, including belt pitch, number of teeth on the pulley, thread pitch on leadscrews, micro-stepping settings, and extruder style.

For the X and Y axis, we use the timing belt/bully system, So the “step per unit” value of the X Y axes is calculated with the following equation.

$$X\ Y\ step\ per\ unit = \frac{motor\ step\ per\ revolution \times stepper\ motor\ driver\ step\ value}{belt\ pitch \times Pulley\ Teeth\ number}$$

In addition, we have:

- motor step per revolution: 200
- stepper motor driver step value: 16
- belt pitch: 2 mm
- Pulley teeth number: 20

So:

$$X\ Y\ step\ per\ unit = \frac{200 \times 16}{2 \times 20} = 80\ step\ per\ unit$$

For the Z axis, use a threaded rods system, so the formula to calculate the “step per unit” value is:

$$Z\ step\ per\ unit = \frac{motor\ step\ per\ revolution \times stepper\ motor\ driver\ step\ value}{threaded\ rod\ step\ per\ revolution}$$

In addition, we have:

- motor step per revolution: 200
- stepper motor driver step value: 16
- threaded rod step per revolution: 8 mm

Therefore, the correct value is:

$$X\ Y\ step\ per\ unit = \frac{200 \times 16}{8} = 400\ step\ per\ unit$$

For the extruder, use a specific formula is not an easy option to solve the step per unit value, so we will use the fourth proportional to find the correct value.

First, we keep the firmware as it is and we do not adjust the default values then open prontaerface and send the “G1 F100 E200” order to the printer, and that makes the printer to extrude 200 mm of filament.

We measure from the end of tube that goes into the extruder 200 mm of filament and mark a line in that point, and after the extruding is done, we measure how long the filament was extruded, so the fourth proportional formula in our case will be:

$$\frac{extruder\ "step\ per\ unet"\ defult\ valeu}{real\ distance\ of\ the\ filament\ extruded} = \frac{extruder\ "step\ per\ unet"\ correct\ valeu}{distance\ of\ the\ filament\ extruded}$$

We have:

- extruder "step per unit" default value: 100
- The real length of the filament extruded: 204 mm
- The length of the filament given in the code: 200 mm

Therefore, the correct value is:

$$E\ step\ per\ unit = \frac{100 \times 200}{204} = 98.04\ step\ per\ unit$$

II.11. Conclusion

In this chapter, we saw different types of 3D printers to make molten fuse, we chose to create 3D printer using Cartesian-XZ-head mechanism and it is similar to Core-XY machine, as we saw the most important material used in printer. With detailed explanation on the most important element of the printer, namely steering engines, as well as explanation of the classification of firmware files.

During the next chapter, we will see the main components of the printer that we will make and some details about how it works, while explaining all the software used.

Chapter III: Components Of FDM 3D Printer

III.1. Introduction

After we did a general look at 3D printing and focused the study on FDM technology and presented its working principle and all its characteristics. We will display in this chapter the basic components needed for our project from the hardware and the software part, and explain their characteristics.

III.2. Constituents of FDM 3D printer

After reviewing many 3D printer models, we decided that our printer would consist of:

Table 5- Overview of the constituents we use

Element		We need it to
1	**ARDUINO Mega board**	Send control signals to the stepper motors and heater as required
1	**RAMPS shield**	Facilitates interfacing the ARDUINO mega.
4	**Stepper motors**	One for extruding the filament, and three for the movement along the X, Y, and Z-axis.
4	**Stepper drivers**	Control the stepper motors.
1	**Extruder**	Push the filament up to the printing head.
1	**Printing head**	Melt the filament.
3	**End-stops**	Define the axes limits.
1	**Full graphic smart controller**	Control the printer and see different useful information like the percentage of printing progress.
1	**Heated bed**	Achieve high-quality models and avoid melting problems.
2	**MOSFET**	Give the power needed for the hotend and heated bed.
2	**Timing belts**	Provide motion transformation in the X and Y axes.
2	**Timing belt pulleys**	
1	**Lead scrow**	Provide the motion transformation in the Z axes.
2	**Lead scrow nut**	
1	**Coupler**	Connect the thread lead screw with the stepper motor.
6	**Linear rod**	Provide linear movement on all axes.
12	**linear bearings**	Facilitate the movement of axes and reduce friction.
4	**Clamp**	Connect the linear bearings to the Y axes.
many	**Aluminum sheets**	Build the base and axes carriers.
many	**Nut, Washers, And screws**	Put all the parts together.

III.3. Hardware

Hardware includes the physical parts of the printer.

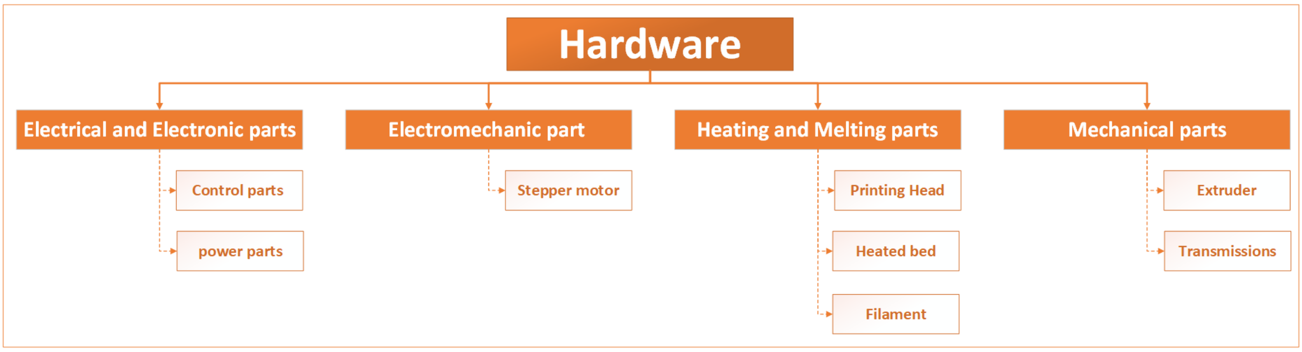


Figure III.1: Flowchart showing the basic hardware for printing a 3D model

III.3.1. Electrical and Electronic parts

Includes any electrical device or element that uses electricity to provide power, Movement, Or control.

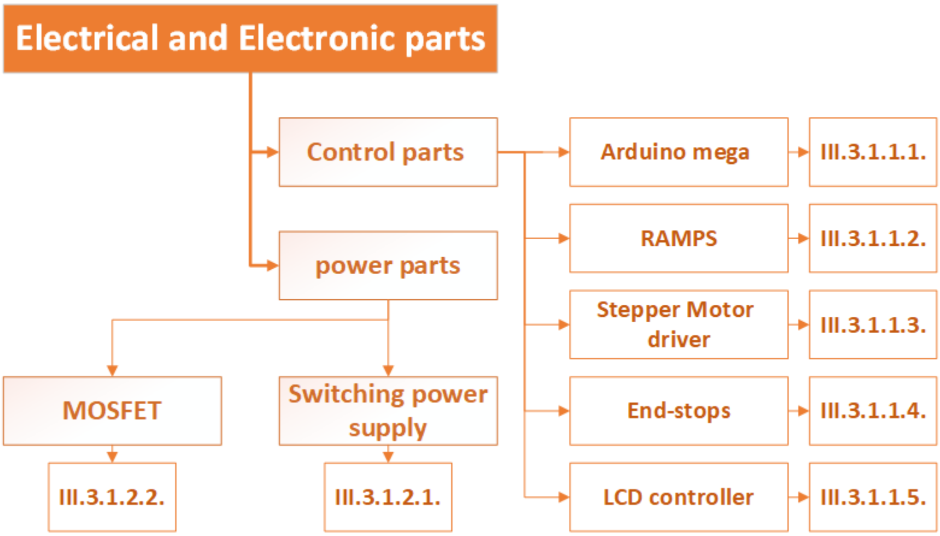


Figure III.2: Electrical and Electronic parts

III.3.1.1. Control parts

III.3.1.1.1. Arduino mega board

III.3.1.1.1.1. Overview

The arduino mega board is an open-source physical computing platform based on a simple i/o board and a development environment that implements the processing/wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on your computer, also it can be programmed with the arduino Software (IDE). [42]

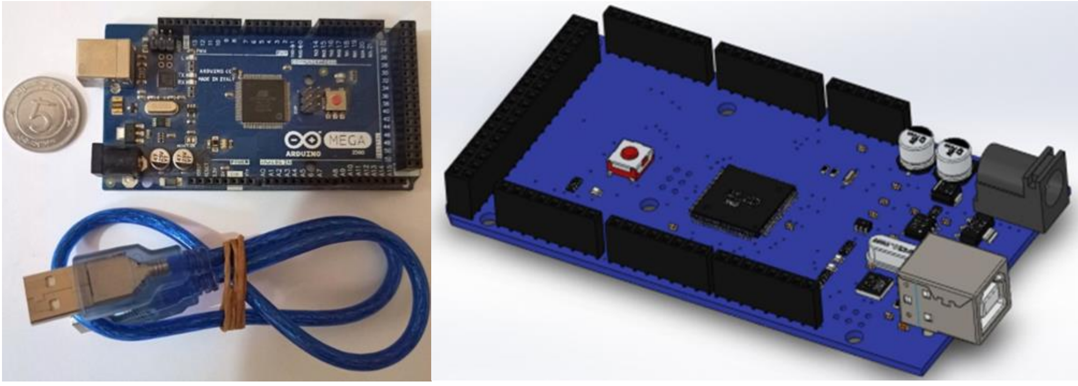


Figure III.3: Model of the arduino mega board

III.3.1.1.1.2. Characteristics

Arduino mega characteristics are shown in the following table:

Table 6- Characteristics of the Arduino Mega board [43]

Model name	Arduino Mega 2560	
Technical specification	Microcontroller	ATmega2560
	Flash memory	256 KB
	Bootloader Flash Memory	8 KB
	SRAM	8 KB
	EEPROM	4 KB
	Quartz oscillator clock frequency	16 MHz
Electrical specifications	Operating voltage	5 V
	Input voltage range (recommended)	7-12 V
	Input voltage range (limit)	6-20 V
Pins specifications	Digital Pins I/O	54
	Digital Pins I/O PWM	14
	Analog input pins	16
	Direct current per pine I/O	40 mA
	Direct current for pines 3.3 V	50 m

III.3.1.1.2. RAMPS board

III.3.1.1.2.1. Overview

RepRap arduino mega pololu shield board (RAMPS) is an open-source "shield" made by RepRap, That can interface the electronic elements with the arduino board. [44]

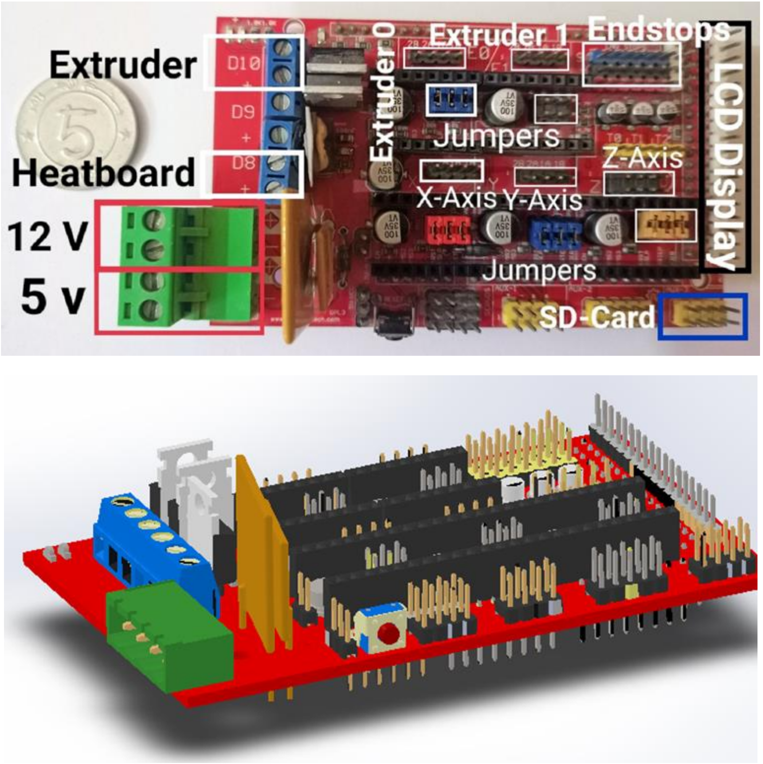


Figure III.4: Model of the RAMPS 1.4 board

III.3.1.1.2.2. Characteristics

RAMPS 1.4 characteristics are shown in the following table:

Table 7- Characteristics of RAMPS 1.4

Model name	RAMPS 1.4	
Technical specification	Interfaces with	Arduino MEGA 2560
	Compatible display controller	RepRap full graphic smart controller
	Compatible stepper driver	A4988 and DRV8825
Electrical specification	Input voltage	12V
Pins specification	Controller display outputs	1
	Stepper motor driver outputs	5
	Limit switch inputs	6
	Thermistor inputs	3
	Power outputs	3 PWM MOSFET's outputs

III.3.1.1.3. Stepper motor driver

III.3.1.1.3.1. Overview

The stepper motor driver is a micro-stepping driver for controlling bipolar stepper motors Which have a built-in translator for easy operation, this means that we can control the stepper motor with just two pins from the controller, One for controlling the steps and the other for controlling the rotation direction. [45]

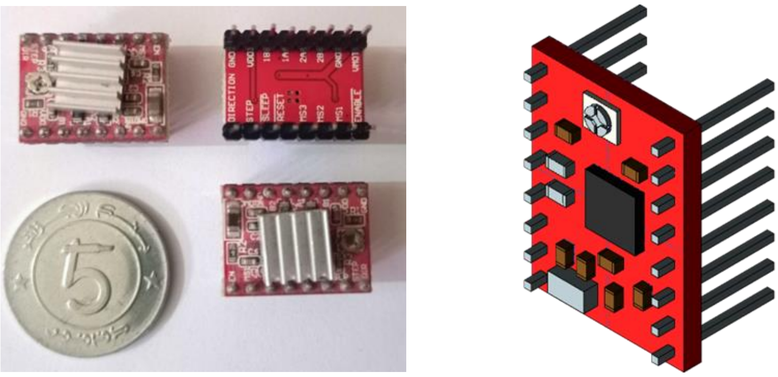


Figure III.5: Model of A4988 stepper drivers with heat-sink

III.3.1.1.3.2. Characteristics

The table below shows the characteristics of the A4988 stepper driver.

Table 8- Characteristics of the A4988 stepper driver [46]

Model	A4988	
Technical specification	Dimensions	15.5 × 20.5 mm (0.6″ × 0.8″)
	Microstep resolution	Full step, ½ step, ¼ step, 1/8 and 1/16 step
Electrical specifications	Max. Operating Voltage	35V
	Min. Operating Voltage	8V
	Max. Current Per Phase	2A
Protection	Short-to-ground protection	yes
	shorted-load protection	yes
	Thermal shutdown circuitry	yes

The figure below shows the circuit diagram for interfacing the A4988 module with a microcontroller to control a stepper motor

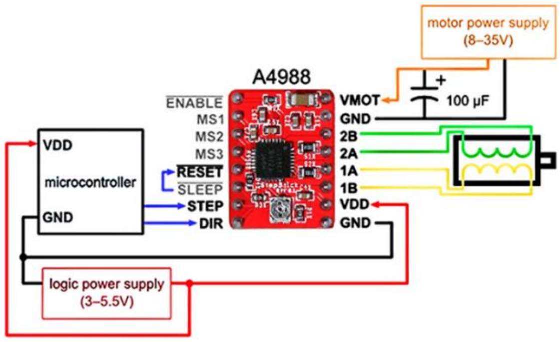


Figure III.6: Circuit of the A4988 stepper driver [47]

III.3.1.1.3.3. The five different resolutions of steps

To choose the resolution of steps (micro-steps) we use the pins MS1, MS2 and MS3, it is enough just to place a jumper on the desired resolution we use the following table: [48]

Table 9- The steps of different resolutions

Microstepping Resolution	MS1	MS2	MS3
Full step	0	0	0
1/**2 step**	1	0	0
1/4 of a step	0	1	0
1/8 of a step	1	1	0
1/16 of a step	1	1	1

III.3.1.1.4. End-stops

III.3.1.1.4.1. Overview

The mechanical end-stop or limit-switch is one of the most basic forms of the end-stops, these switches detect when an axis has touched a minimum or maximum bound to protect the hardware components from damage while moving. [49]

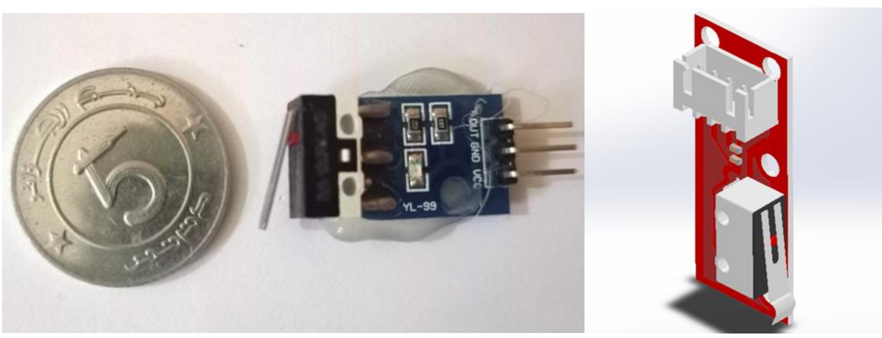


Figure III.7: Model of the end-stop

III.3.1.1.4.2. Working principle

A trigger is positioned to a simple mechanical switch by a blade (the red one), So when the printer axis reaches the end/start of its motion and pulls that trigger, The switch will change its position.

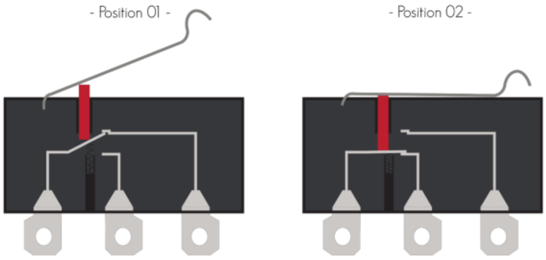


Figure III.8: The end-stop positions

III.3.1.1.5. Full graphic smart controller (LCD controller)

III.3.1.1.5.1. Overview

The RepRap full graphic smart controller is intended to provide an easy and simple solution to interact with a 3D printer, it contains an SD-Card reader, A 128 x 64 dot matrix LCD, A buzzer, And a rotary encoder that makes navigation quick and easy. [50]

Figure III.9: Model of the LCD controller

III.3.1.1.5.2. Characteristics

Table 10- Characteristics of the LCD controller

Model name	RepRap Discount Full Graphic Smart Controller	
Technical specification	Dimension	93mm×87mm×87mm(L×W×H)
Display specification	Display	128columns x 64lines
	Display Size	3 inches
Electrical specification	Supply Voltage	5V

This controller has two 10-pins (2 rows with 2.54mm pitch) box connectors marked EXP1 and EXP2 (10-pins IDC connector), It can be connected with the smart adapter shown below with 18-pins.

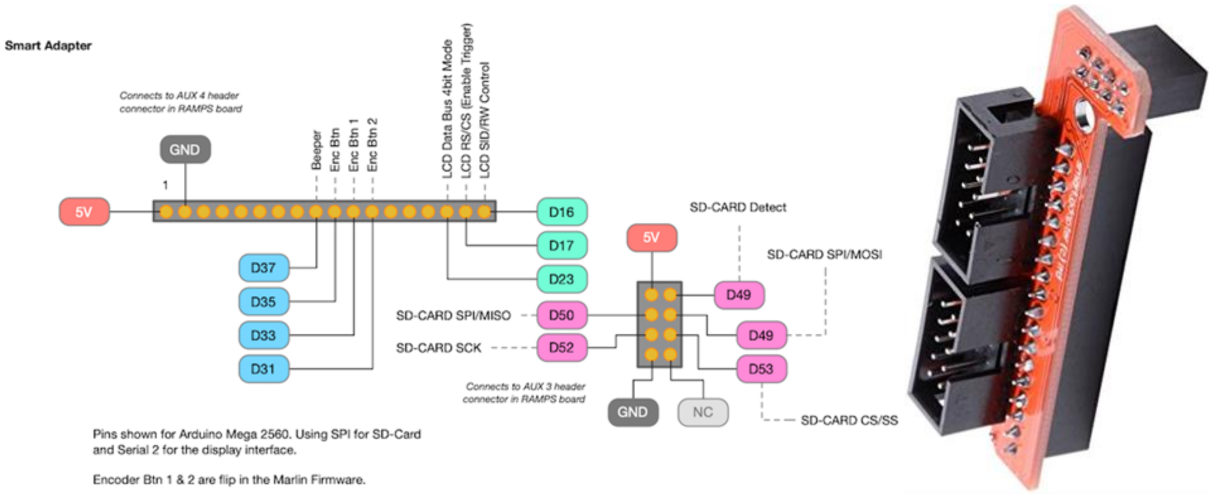


Figure III.10: Wiring diagram of the LCD controller with the smart adapter [51]

III.3.1.2. Power parts

III.3.1.2.1. Switching power supply

III.3.1.2.1.1. Overview

A power supply is an electrical device that converts the electric current (AC) that comes from a power source to the voltage value (DC) necessary for powering a load.

There are two designs for power supplies, A switching power supply and a linear power supply.

A switching power supply design is a newer methodology developed to solve many problems associated with linear power supply design, Like transformer size and voltage regulation. [52]

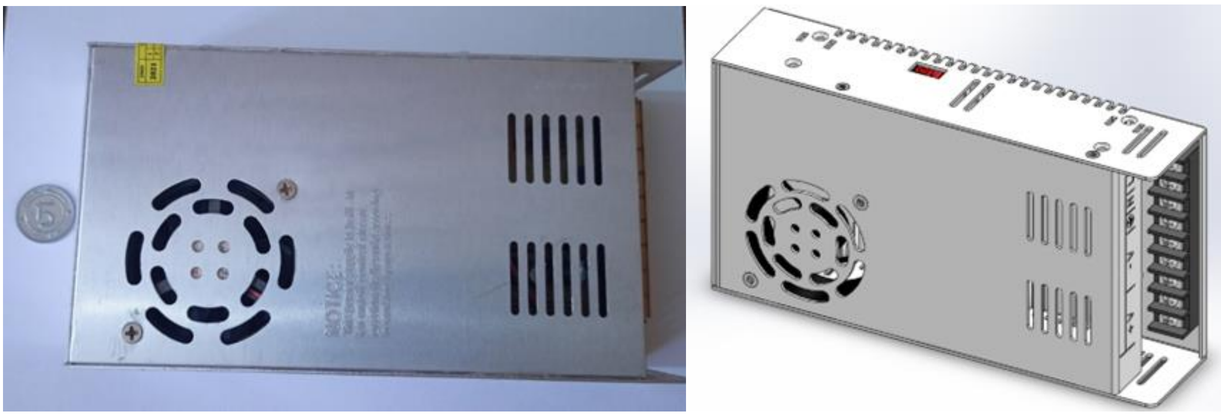


Figure III.11: Model of the power supply

III.3.1.2.1.2. Working principle of the Switching power supply

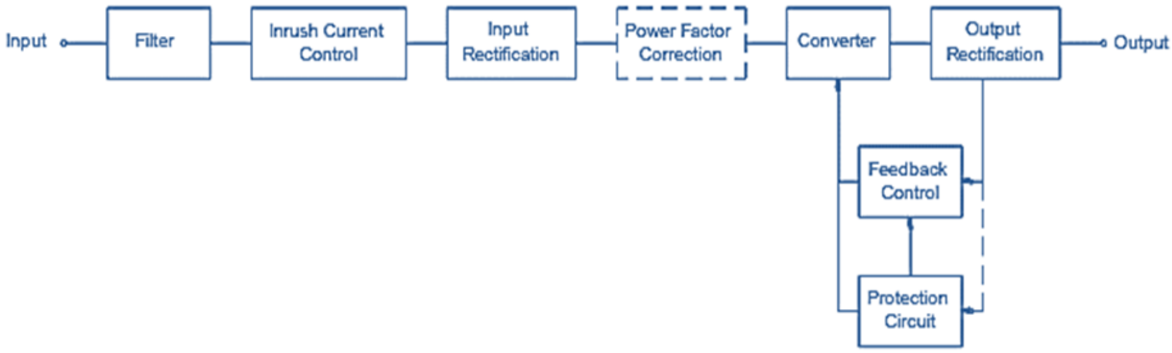


Figure III.12: Switching power supply Block diagram

a) **EMI Filter:** The built-in filter reduces the EMI generated from the S.P.S.
b) **Inrush Current Suppressor:** Inrush current occurs at the time of power-on of the S.P.S. If the inrush current is too large, the S.P.S. might be damaged, and the power distribution system could be adversely influenced. Thus, an inrush current suppressor is installed inside each S.P.S. to limit the high current.
c) **Input Rectifier:** It rectifies the AC input voltage to a DC level.
d) **Power Factor Correction (PFC):** The active/passive PFC circuit upgrades the power factor (PF) figure and approximates the waveform of input current to a sine wave, to be compliant with the harmonic current regulation and reduce reactive power.
e) **Converter:** It converts the DC voltage to a high-frequency signal, and the signal is increased or decreased by a high-frequency transformer.
f) **Output Rectifier:** It rectifies the DC pulses to a steady DC level.
g) **Feedback Control:** It regulates the output voltage to a steady level to respond to the variation of loads and AC input voltage.
h) **Protection Circuit:** The protection circuits consist of over-voltage, over-temperature, and over-current (overload) protection, etc. [53]

III.3.1.2.1.3. Characteristics of the switched power supply

The following table shows the characteristics of the power supply we use.

Table 11- Characteristics of the power supply [54]

Model	8PS120360DCU	
Input	Voltage range	90~132VAC/170~264VAC(selected by switch),235~373VDC
	frequency	47~63HZ
	AC current (max)	6.5A/115V 4A/230VAC
	Efficiency	83%
Output	DC voltage	12V
	Current range	0~30A
	Rated power	360W
Protection	Overload, Short-circuit	yes
Others	Dimension	215mm×115mm×50mm (L×W×H)
	Net Weight	970GR

III.3.1.2.2. MOSFET

III.3.1.2.2.1. Overview

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device used for switching purposes and amplification of electronic signals in electronic devices. [55]

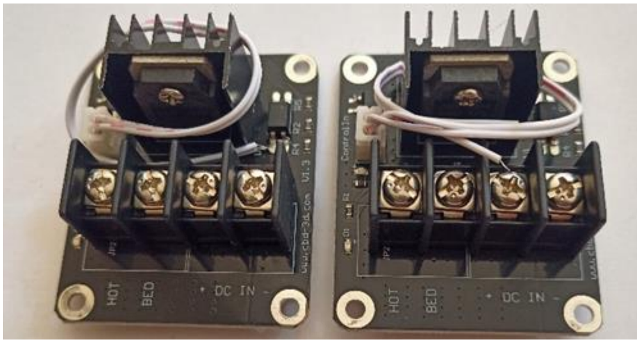


Figure III.13: Model of the MOSFET (Heated Bed power expansion module)

The high current of the heated bed brings many problems to the RAMPS board because all the current for the bed has to go through one connector in adding to all the other current for the hotend, the default connectors cannot handle that much of the current, so we use MOSFETs to power the hotend and the heated bed, to avoid over current problems.

III.3.1.2.2.2. Characteristics

The MOSFET can power the heated bed up to 25A and accepts PWM input.

Table 12- Characteristics of the MOSFET

Model name	NCEP01T18T Heated bed MOSFET PCB	
Technical specifications	Dimensions	60mmx50mmx33mm(L×V×H)
Electrical specifications	Input voltage	12-24V
	Control voltage	12-24V
	Max current	25A

III.3.2. Electromechanic part

Electromechanic is the combination of electrical and mechanical techniques.

Figure III.14: Electromechanic part

III.3.2.1. Stepper motor

III.3.2.1.1. Overview

We talked about the stepper motors enough in the second chapter, And now we will use the stepper motors in the extruder and the X, Y, and Z axes.

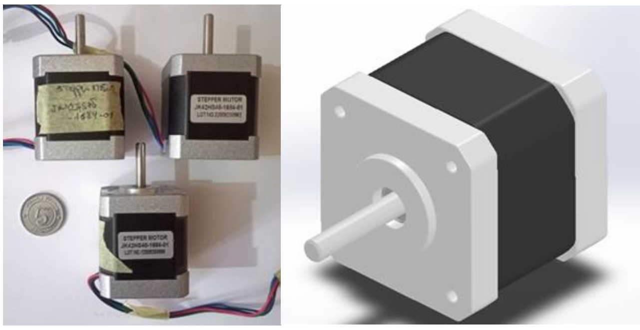


Figure III.15: Model of the NEMA-17 stepper motor

III.3.2.1.2. Characteristics

The following table shows the characteristics of the stepper motor we use. [56]

Table 13- Characteristics of the NEMA-17 stepper motor

Model number	NEMA-17 JK42HS48-1684-01	
Technical specification	Size	42.3mm x 42.3mm x 48mm (L×W×H)
	Weight	280 g
	Type	Hybrid
Mechanical specifications	Step angle(degrees)	1.8° (±5%)
	Number of steps	200 steps
	Holding torque	4.4Kg.cm
Electrical specifications	Number of phases	2 phases
	connection	4 line
	Current /Phase	1.68A
	Resistance /Phase	1.65Ω
	Inductance /Phase	3.2mH

The figure below shows the NEMA 17 wiring diagram

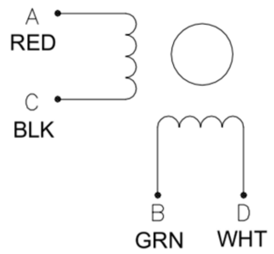


Figure III.16: Diagram of the NEMA-17 stepper motor [56]

III.3.3. Heating and melting Parts

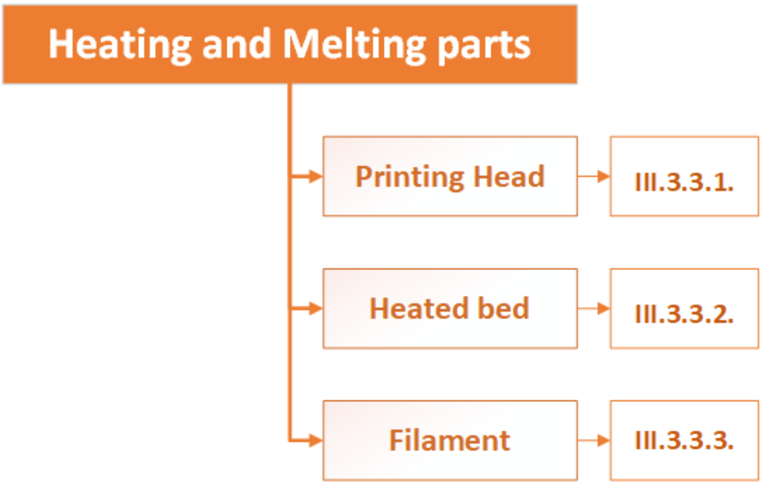


Figure III.17: Heating and melting Parts

III.3.3.1. Printing Head

III.3.3.1.1. Overview

The printing head is also known as the hot-end, is the part of the 3D printer responsible for melting the filament to be extruded on the printing base, to form 3d object layers.

A side view of the printing head that we will be using is shown in the figure below.

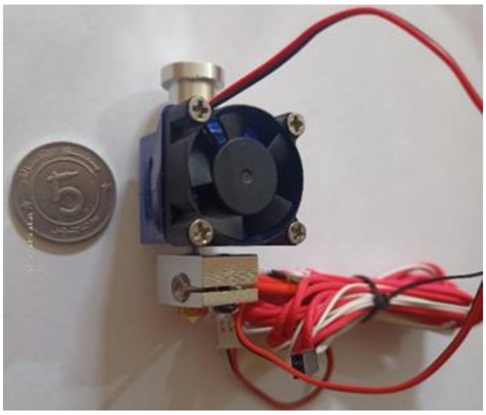


Figure III.18: Model of the printing head

III.3.3.1.2. Characteristics

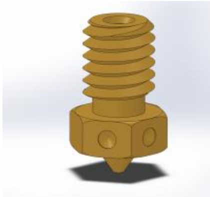
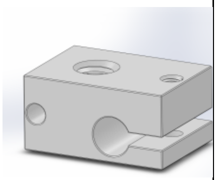
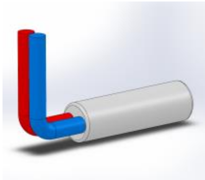
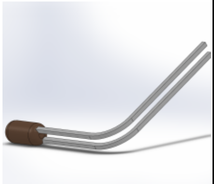
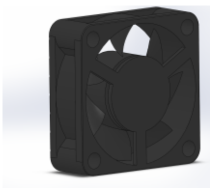
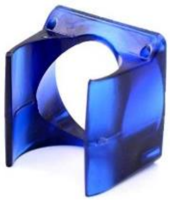
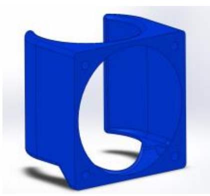
The following table shows the Characteristics of the E3D V6 hotend

Table 14- Characteristics of the E3D V6 printing head [57]

Model number	E3D V6	
Technical Specification	Aluminum block size	20 mm x 20 mm x 10 mm (L×W×H)
	Weight	280 g
	Material	Aluminum & Stainless Steel & Brass
	Thermistor and heater cable length	1M
	Nozzle size	0.4mm
	Throat pipe length	30mm
Electrical Specifications	Installation type	External thread connection
	Connection	4 line
	Operating temperature range	-40°C to +260°C (-40°F to +500 °F)
	Heating tube power	40W
	Heating tube voltage	12V

III.3.3.1.3. Printing head parts

Table 15- printing head parts [58]

Element	Photo	3D model	Role
Nozzle			This is the part where the filament comes out. It takes in the molten filament and tapers down to the nozzle size.
Heater Block			The heater block joins the nozzle to the heat break and holds the heater cartridge and thermistor.
Heater Cartridge			This ceramic heater cartridge is responsible for heating the hot end.
Thermistor			This part is a small glass bead with two wires attached, it can sense the temperature of the heat block.
Heat Sink			the purpose of the heat sink is to cool down the cold side of the heat break. It is usually cooled with a fan
Heat Break			this is the part where the heat block connects to the heat sink. it takes the form of a Throat thin tube made of stainless steel.
Cooler fan			You cool the Heat Sink to prevent heat from moving from the hot part to the cold part.
Fan holder			As its name suggests, it holds the fan and concentrates the airflow on the heat sink

III.3.3.2. Heated bed

III.3.3.2.1. Overview

It Is a bed that contains a heating circuit fixed under it, it allows a good distribution of heat on the plate of work.

Printing on a heated bed allows the printed part to stay warm during the process of printing and allows even the shrinkage of the plastic material. The heated bed generally gives a superior quality finish built with materials such as ABS and PLA. [59]

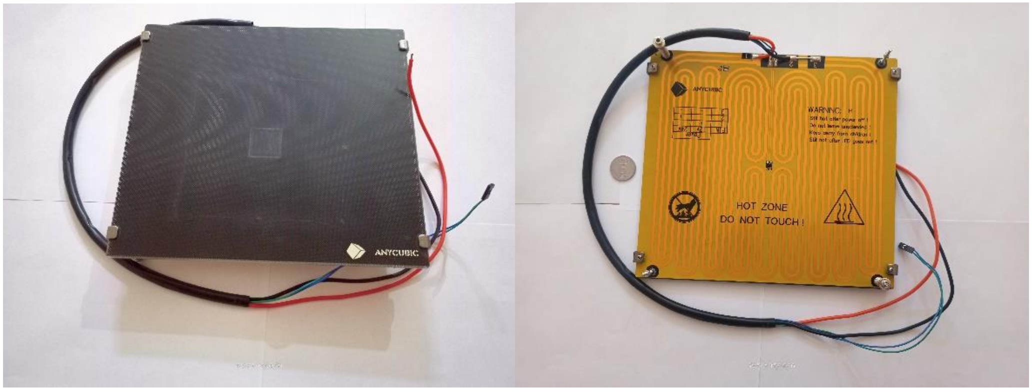


Figure III.19: Model of the heated bed

III.3.3.2.2. Characteristics

Table 16- Characteristics of the heated bed [60]

Model number	Anycubic Ultrabase	
Technical Specification	Material	Special Glass + microporous coatings
	Item size	220mm × 240mm × 5.5mm (L×W×H)
	Color	Black
Electrical Specifications	Heat Bed Power	140-145W
	Heat Bed Voltage	12V
	Heat Bed Resistance	around 0.9 ohm
Thermal Specification	Max Temperature	120 Degree Celsius
	The recommended temperature for PLA	50-70 Degree Celsius
	The recommended temperature for ABS	100-120 Degree Celsius

III.3.3.3. Filament (PLA)

The filament is the primary supplier of printer and raw material for printed model.

III.3.3.3.1. Overview

Polylactic Acid (PLA) is the most common material used in consumer 3D printers. It's made from starch extracted from plants like corn and wheat, so it's a biodegradable material that can be composted. [61]

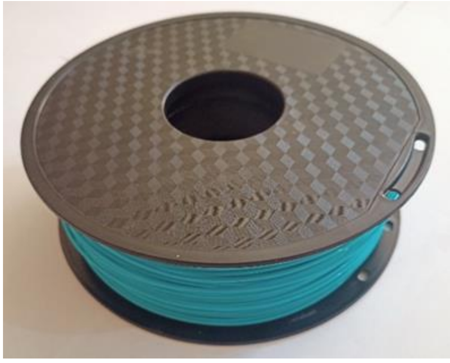


Figure III.20: The PLA filament spool

III.3.3.3.2. Characteristics

Table 17- Characteristics of the PLA filament

Model number	PLA spool filament	
Technical Specification	Material	PLA
	Filament diameter	1.75 mm
	Color	Sky Blue
Thermal Specification	Printing head recommended temperature	190-230 degrees celsius
	Heated bed recommended temperature	100-120 degree celsius

III.3.4. Mechanical parts

will show the various mechanical parts for allowing the transmission, and the transformation of movements.

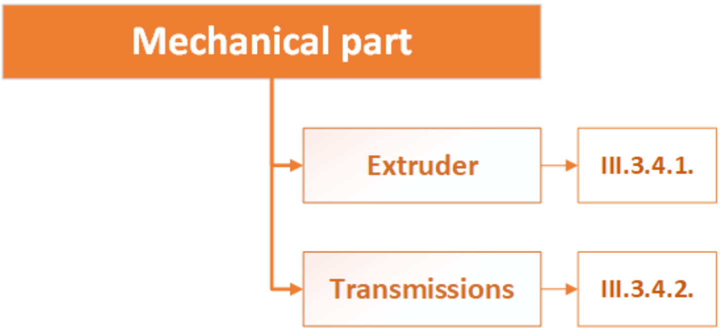


Figure III.21: Mechanical parts

III.3.4.1. Extruder

III.3.4.1.1. Overview

The extruder is responsible for sending the correct amount of filament to the printing head where it's melted and extruded down into 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 body to the hot end. This is called a Bowden tube. The lament 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. [49]

In this project, we use the Bowden extruder with an E3D V6 print head.

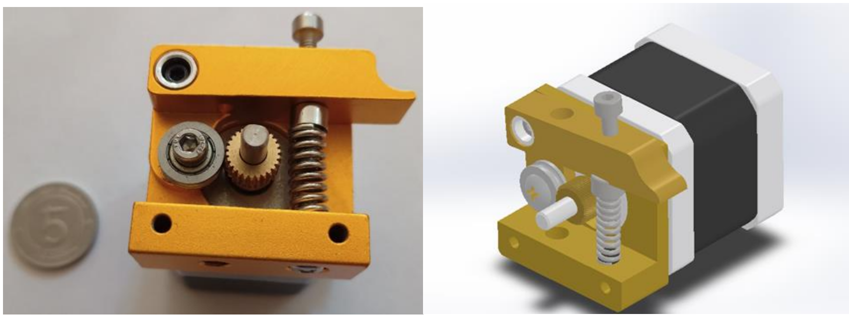


Figure III.22: Model pf the MK8 extruder with its stepper motor and the cooling fan

III.3.4.1.2. Characteristics

Table 18- characteristics of the MK8 extruder [68]

Model number	MK8	
Technical Specification	Material	Steel
	Color	Golden
	Compatible stepper motor	NEMA-17 JK42HS48-1684-01
Thermal Specification	Normal temperature	190 ° -230 °
	maximum temperature	less than 280 °
Printing specification	Filament diameter	1.75 mm
	Nozzle diameter	0.4mm
	Motion shaft speed	40mm/s
	Nozzle flow rate	about 24cc/h

III.3.4.1.3. The MK8 extruder elements

The Mk8 extruder comes with many components including the stepper motor and the cooling fan.

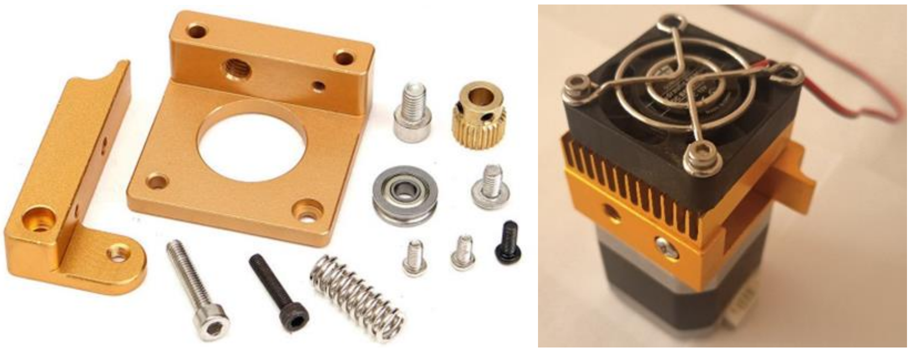


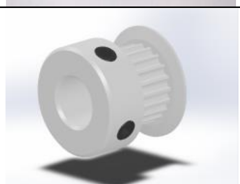
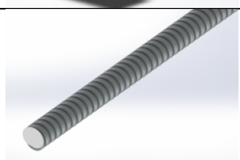
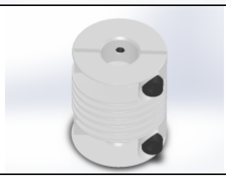
Figure III.23: The MK8 extruder Part [62]

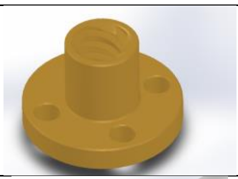
III.3.4.2. Transmissions

Transmissions allow rotational motion to be linear or vice versa and help make it easier to move by reducing friction between moving parts to get the physical motion required for printing.

Here we will only display the transmissions we have used, displaying their shapes without mentioning their characteristics.

Table 19- Transmissions and ther description

Elements		Description
Timing belt		Used in the X-Y axis to move it horizontally by converting the rotational motion of the stepper motor into linear motion
Timing belt pulley		
Lead scrow		Used in the Z-axis to provide vertical motion by converting the rotational motion of the stepper motor into the linear motion.
Coupler		

<table>
<tr><td>Leadscrew nut</td><td></td><td></td></tr>
<tr><td>Linear Rod</td><td></td><td rowspan="3">Used in the X-Y axis to enable these axes to slide linearly.</td></tr>
<tr><td>Linear bearing</td><td></td></tr>
<tr><td>Linear bearing block</td><td></td></tr>
<tr><td>Clamp</td><td></td><td>We need it to install the linear bearing with the base of the Y-axis.</td></tr>
</table>

III.4. Software

The software part is important for the realization of our project since the operation of the mechanical part and the hardware part of the project is directly related to the software used to model the different mechanical parts as well, as the development of firmware and control circuits.

As we said before, to print a 3D model, we need different software:

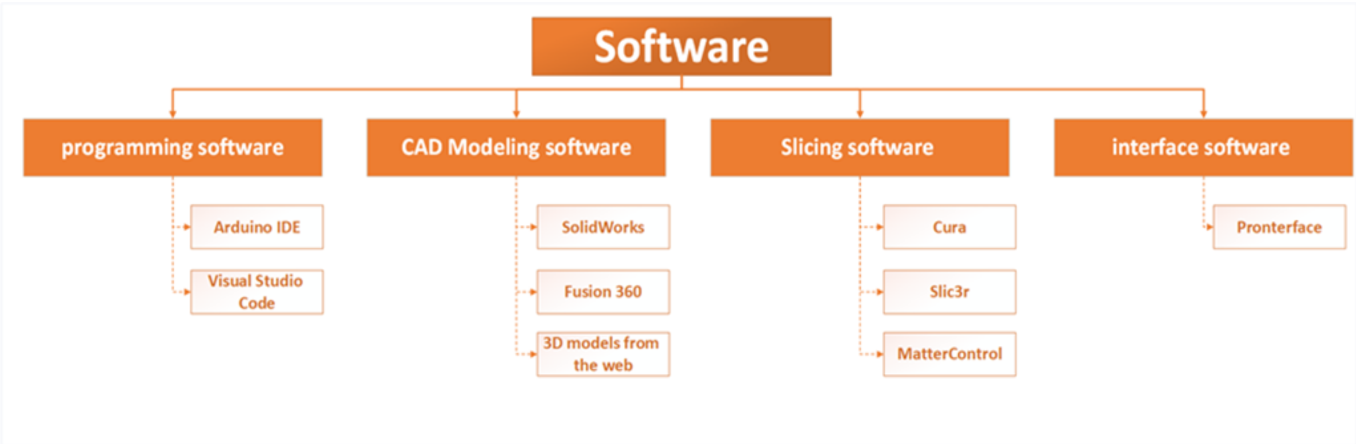


Figure III.24: Flowchart showing the basic software for printing a 3D model

But all these programs can be reduced to 3 or 4 basic programs to produce a 3D model, as shown in the following figure:

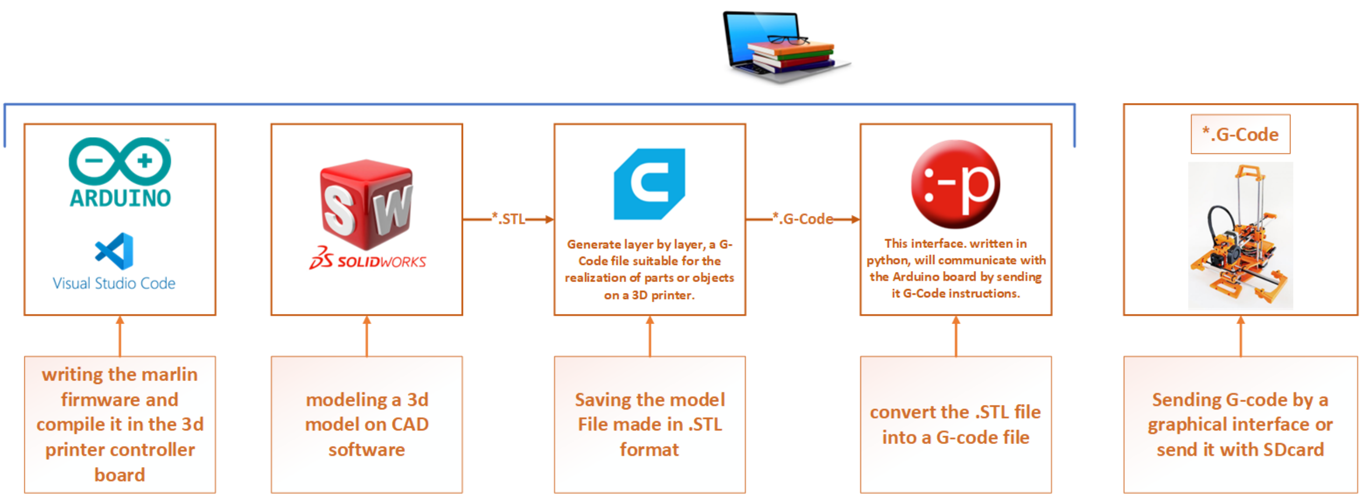


Figure III.25: Flowchart of how 3D printer works

III.4.1. Programming software

III.4.1.1. Arduino IDE

III.4.1.1.1. Overview

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. This software can be used with any Arduino board. [63]

Figure III.26: Arduino IDE logo

III.4.1.1.2. The general structure of the program

The program has a very simple interface, which in turn consists of the menu bar, the toolbar, program writing area, ongoing actions message area, and console for displaying compilation messages.

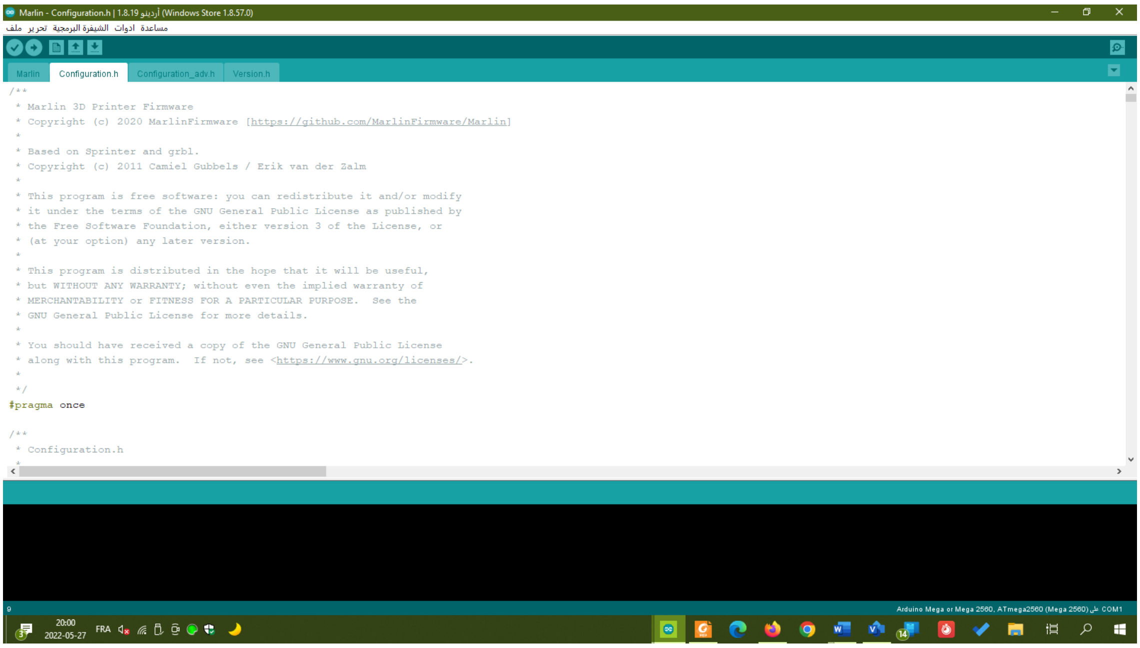


Figure III.27: Arduino IDE software interface

III.4.1.2. Visual studio code

III.4.1.2.1. Overview

Visual Studio Code, (VS Code), is a source-code editor made by Microsoft for Windows, macOS, and Linux. It has many features including support for debugging, intelligent code completion, syntax highlighting, snippets, and code refactoring. [64]

Figure III.28: Visual studio code logo

III.4.1.2.2. The general structure of the program

Visual Studio Code interface has a simple and intuitive layout that maximizes the editor's space while leaving ample room to browse and access the full context of your folder or project. The UI is divided into five areas: Editor Area, Side Bar, Status Bar, Activity Bar, and Panels.

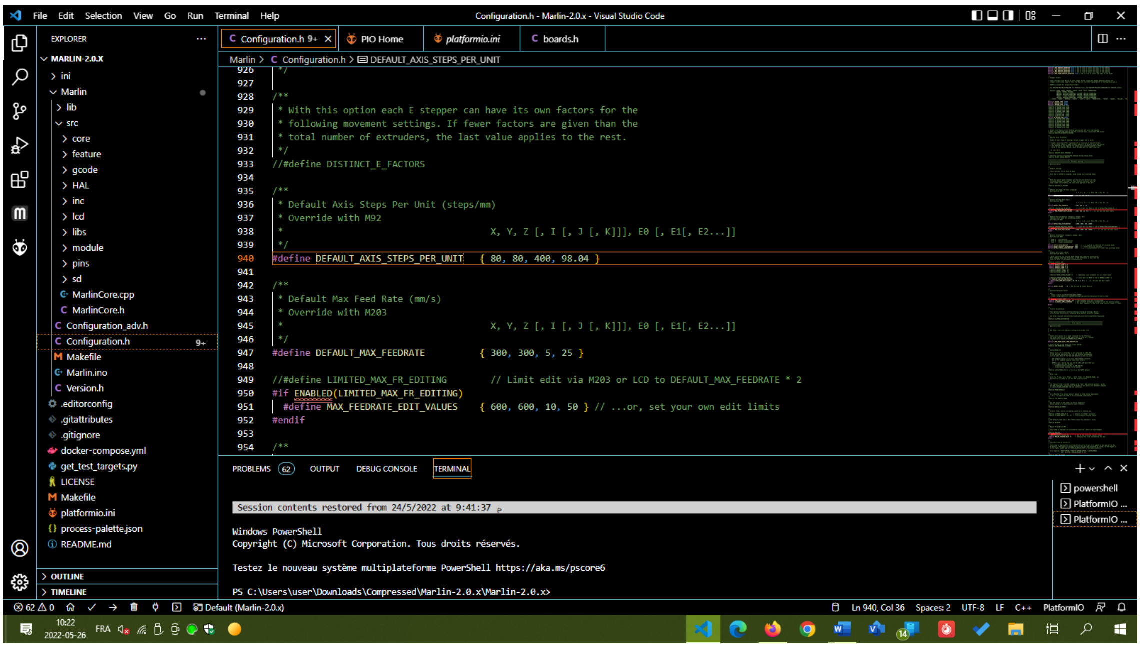


Figure III.29: Visual Studio Code software interface

III.4.2. CAD Modeling software

The first step to printing a real object is to create a virtual 3D digital model of it using a program, often called CAD (Computer Aided Design). There are many of these programs for the most popular platforms (Windows, Mac OS X, and Linux), and some are available for free or as open source. CAD software is used in all the architectural and engineering industries and is always present via rapid prototyping. [65-66]

III.4.2.1. Solidworks

III.4.2.1.1. Overview

SolidWorks is a very powerful and easy-to-handle CAD (Computer Aided Design) software dedicated to 3D design and modeling. It is widely used in industry for the manufacture of different mechanical, hydraulic, and electrical parts as well as the assembly of parts and the design of machines and devices from A to Z. [67]

Figure III.30: Solidworks logo

III.4.2.1.2. The general structure of the program

Getting started with SOLIDWORKS can be a challenge, especially for new users coming from 2D CAD programs, because it has many menus including a: menu bar, command manager, feature Manager design tree, configuration manager, and more.

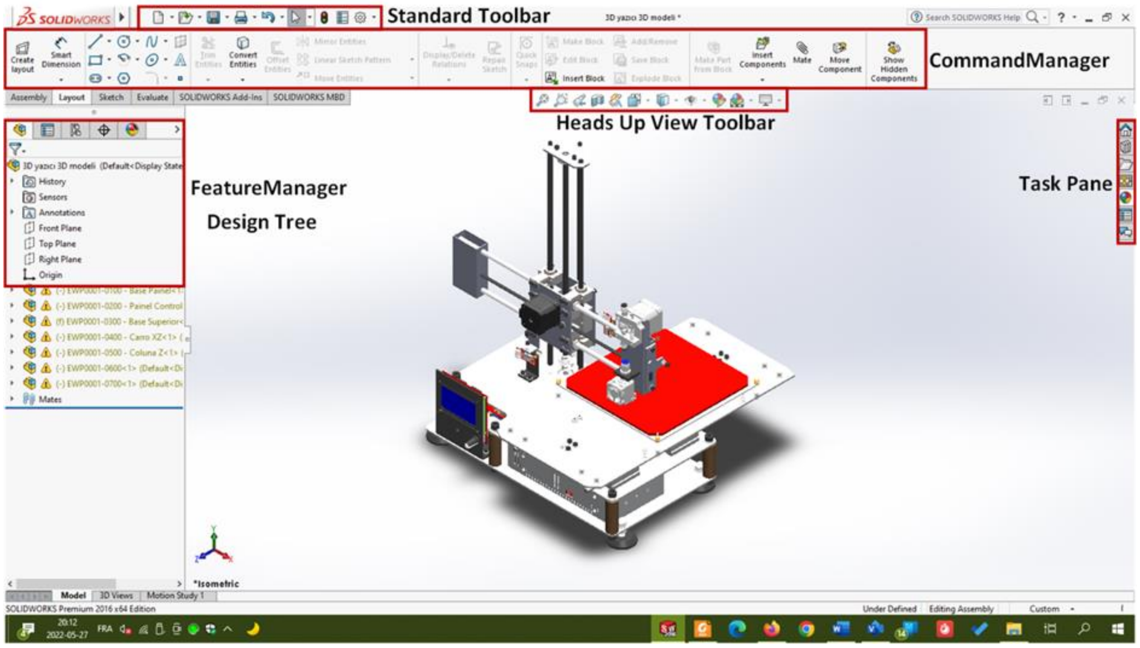


Figure III.31: SolidWorks software interface

III.4.2.2. Fusion 360

III.4.2.2.1. Overview

Fusion 360 is among the most popular CAD software for hobbyist and amateur 3D printing projects. It offers a full array of 3D modeling features for creating parts from scratch, and comprehensive mesh editing tools for model modification. [68]

Figure III.32: Fusion 360 logo

III.4.2.2.2. The general structure of the program

The program consists of 9 main sections: Data panel, Application bar, Toolbar, Browser, Together in the drawing area, ViewCube, Marking menu, Navigation bar, and Timeline. [69-70]

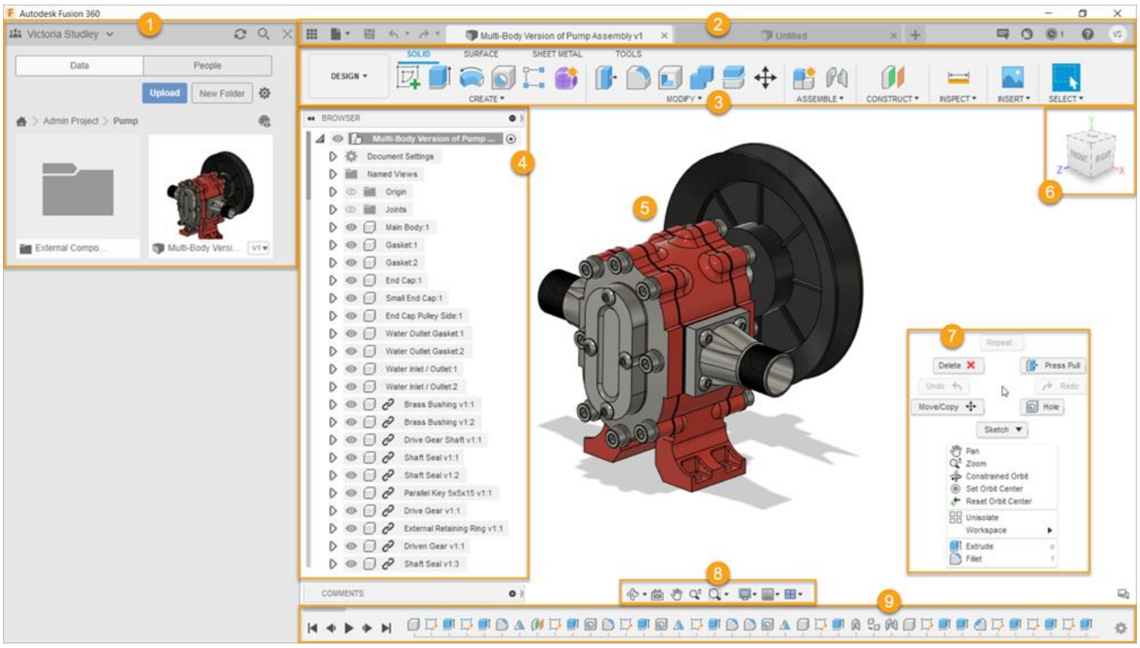


Figure III.33: Fusion 360 software interface

III.4.2.3. 3D models from the web

Many websites provide 3D models for downloading and printing, even editing And from these websites we mention.

III.4.2.3.1. Autodesk tinkercad

Tinkercad is a free online program that runs in a web browser, and has many features such as 3D design, electronics, and coding. Especially for new learners, it offers a simple interface with easy-to-use menus compared to SOLIDWORKS, Websites. [71]

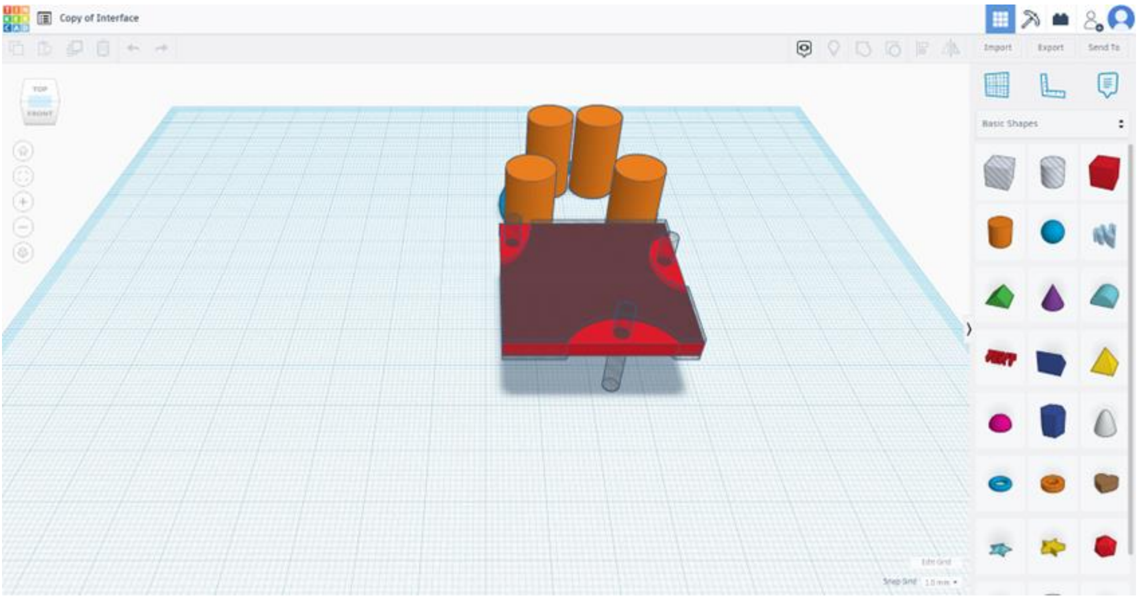


Figure III.34: Autodesk tinkercad website interface

III.4.2.3.2. MakerBot Thingiverse

MakerBot's Thingiverse is a flourishing design community for making, discovering, and sharing Hundreds of 3D printable things, Websites [72].

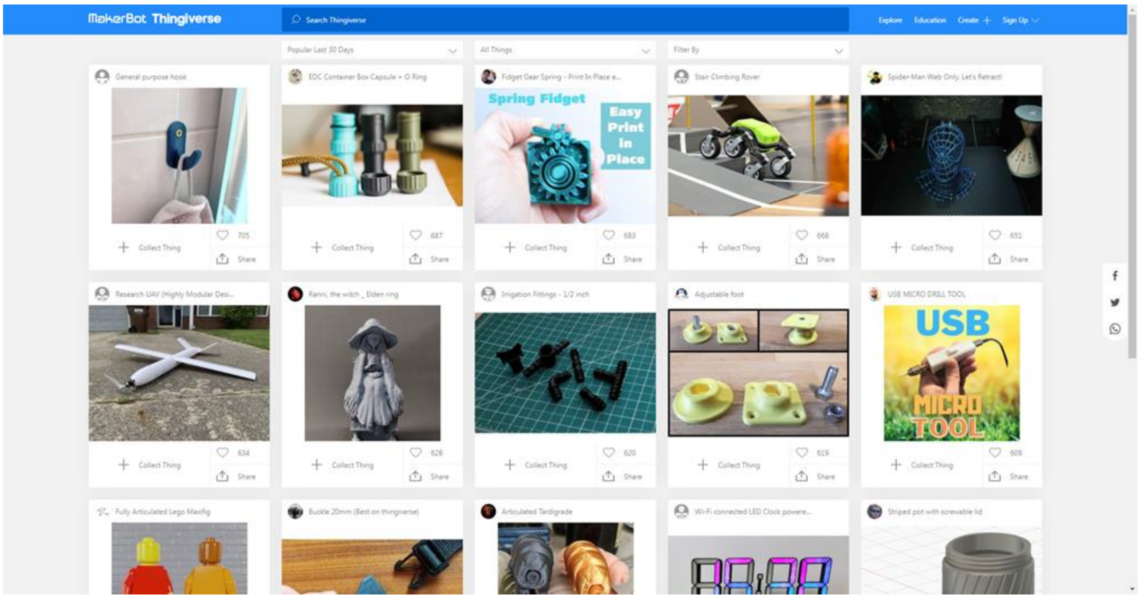


Figure III.35: MakerBot Thingiverse website interface

III.4.2.3.3. GrabCAD

GrabCAD isn't for simply downloading free STL files. however It has many CAD models in the library, and lots of them also are available in STL format. You can download 3D models in several formats and convert them into STL files to print them, Websites [73].

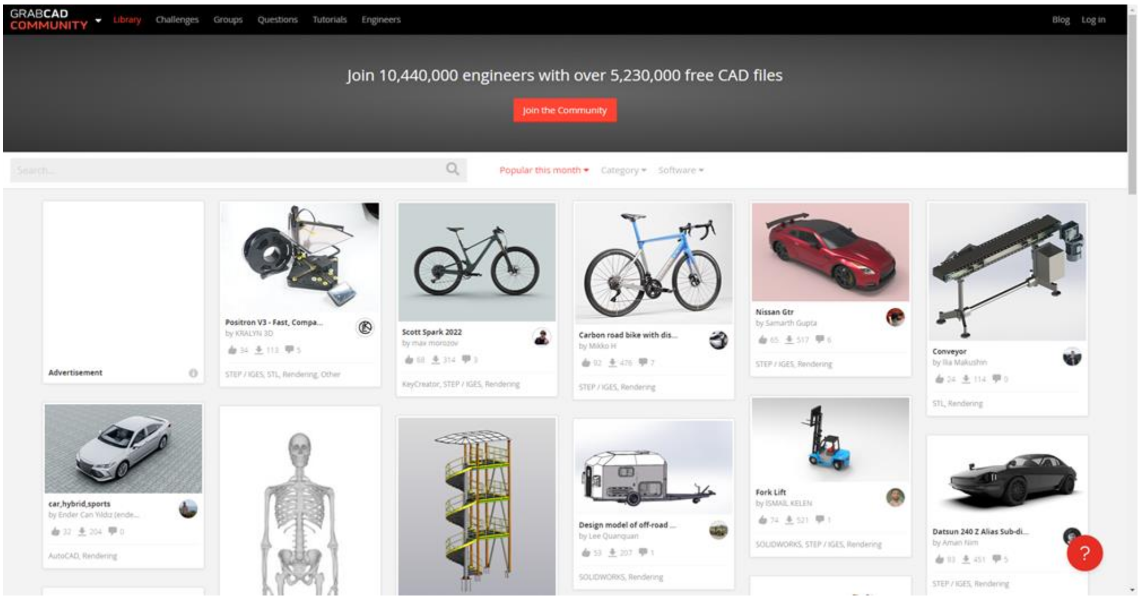


Figure III.36: GrabCAD website interface

III.4.2.3.4. MyMiniFactory

This site offers very powerful quality models and all the objects are curated, which means every object uploaded on MyMiniFactory has been test-printed on desktop 3D printers, Websites [74].

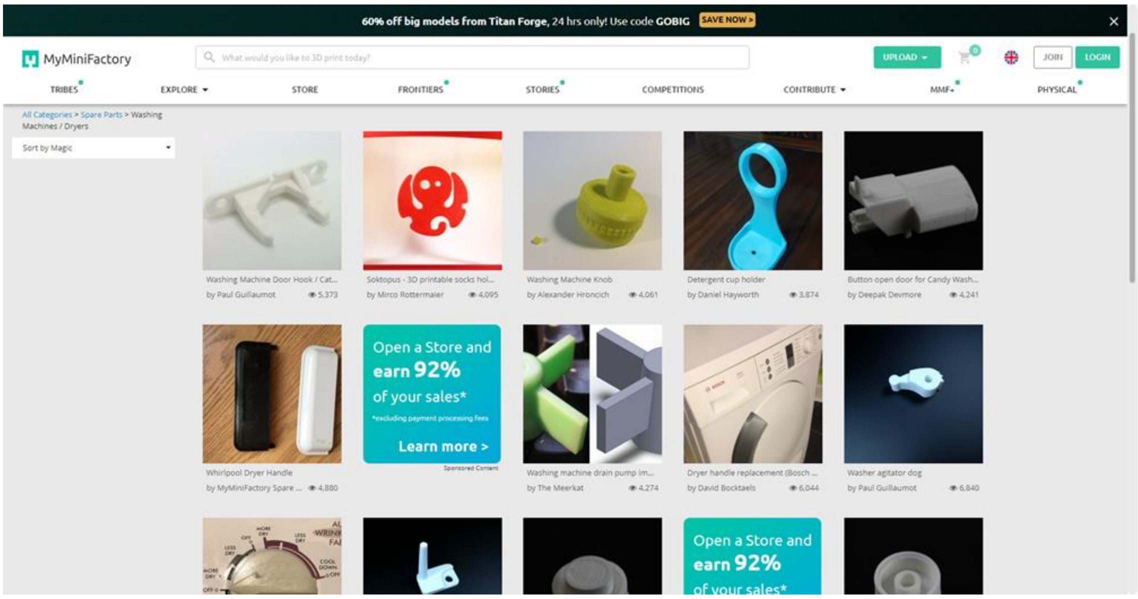


Figure III.37: MyMiniFactory website interface

III.4.3. Slicing software

III.4.3.1. Slic3r

III.4.3.1.1. Overview

Slic3r software is a 3D slicing engine for 3D printers. It can generate G-code from 3D CAD files (STL or OBJ).

the information is written in a language called G-Code, already used since the 60s it still allows today to control machine tools with control digital. [75]

Figure III.38: Slic3r logo

III.4.3.1.2. The general structure of the program

Slic3r's user interface is very useful and wastes no time in introducing relevant features and settings, ready for quick use while slicing.

A notable feature of Slic3r's user interface is the presence of tooltips in the internal menus. These tend to provide quick help, as they explain the purpose of each value or parameter. [76]

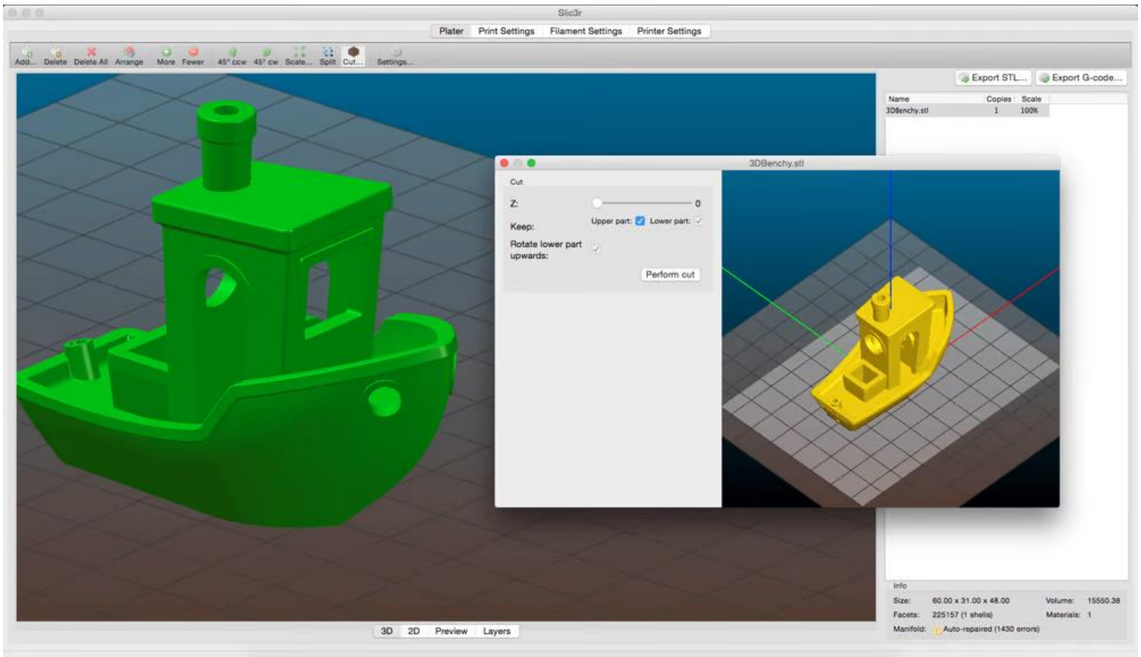


Figure III.39: Slic3r software interface

III.4.3.2. Cura

III.4.3.2.1. Overview

Cura is an open-source slicing application for 3D printers, created by Ultimaker Company in which you can modify the printing parameters and then transform them into G-code. [77]

Figure III.40: Cura logo

III.4.3.2.2. The general structure of the program

The Cura interface is not that difficult, especially with the structured interface, which contains the basic menus in the interface in a simple and orderly manner, and from these lists: Printer selection panel, Print settings panel, Camera position tool.

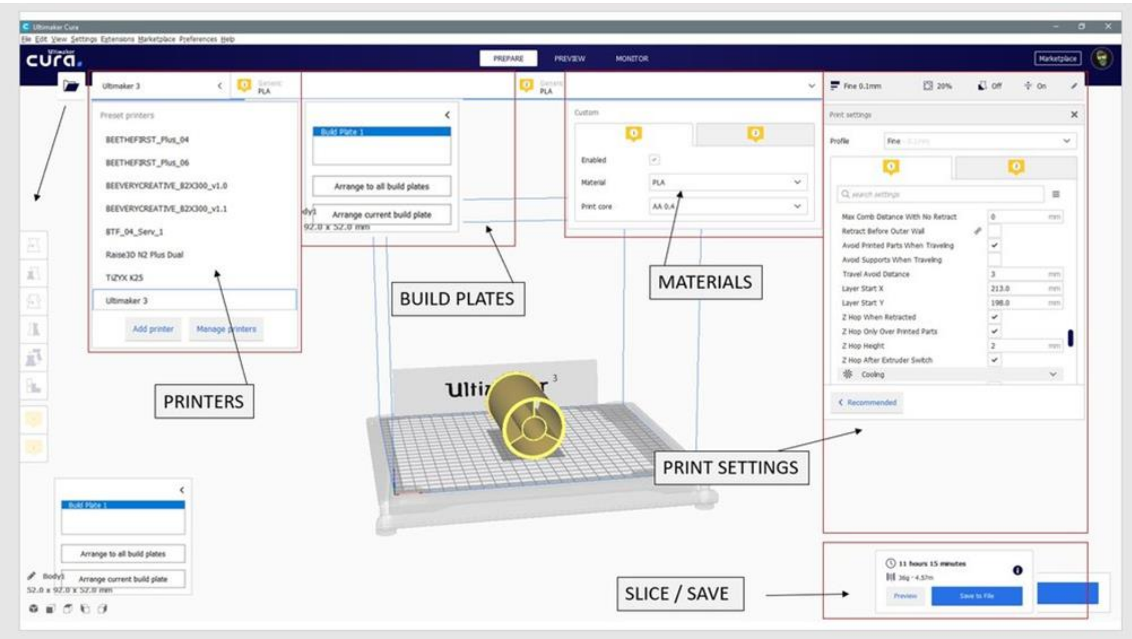


Figure III.41: Cura software interface

III.4.3.2.3. G-Code Overview:

G-code is a name of numerical control language for programming Computer Numerical Control (CNC) devices, it's the must language used to control CNC machines (Laser cutter, milling machine, 3D printers ...).

Originally the language is designed to describe the control and movement telling the stepper motors specifically when to move and where. [78]

III.4.3.2.3.1. G-Code commands

There are several G-code commands. For our case for the Marlin 3D printer firmware, we will use only the ones we need.

The following table show some of the commands used and their description.

Table 20- some of the g-code commands used [79]

commands	code	Description	Example	
Motion	G0-G1	add a linear move to the queue to be performed after all previous moves are completed.	G0 X12	move to 12mm on the X-axis
			G1 X90.6 Y13.8	move to 90.6mm on the X-axis and 13.8mm on the Y-axis
Units	G21	Set units to millimeters. In this mode, all positions, offsets, rates, etc., are interpreted as millimeters.	G21	set units to millimeters
calibration	G28	used to home one or more axes	G28	Home all axes
			G28 X Z	Home the X and Z axes
	G42	moves the nozzle to the location corresponding to a specific coordinate in the bed leveling mesh	G42 I0 J0	front left corner
			G42 I4 J4	center
Control	M17	can be used to enable one or more steppers (X,Y,Z,E).	M17	Enable power on all stepper motors
	M81	Turn off the high-voltage power supply	M81	power off
Thermal	M106	Turn on one of the fans and set its speed	M106 S200	Turn on the fan at 200/255 DC
	M104	Set a new target hot end temperature and continue without waiting.	M104 S185	Set target temperature for the active hot-end

III.4.3.3. MatterControl

III.4.3.3.1. Overview

MatterControl is a slicing tool with built-in modeling software for your desktop computer. MatterControl integrates the MatterHackers website, linking directly to tutorials and products. The plus side about it is that there's also a cloud-based repository of designs and projects, with the ability to save projects and access them from another computer. When using the software as a host, it can even log in and view the progress of remote printing via the Internet. [80]

III.4.3.3.2. The general structure of the program

The layout of the program is rather simple and similar to a web browser, in which different tabs can be opened for different slicing profiles. This is very useful if you have multiple 3D printers, each with their own profile. [81]

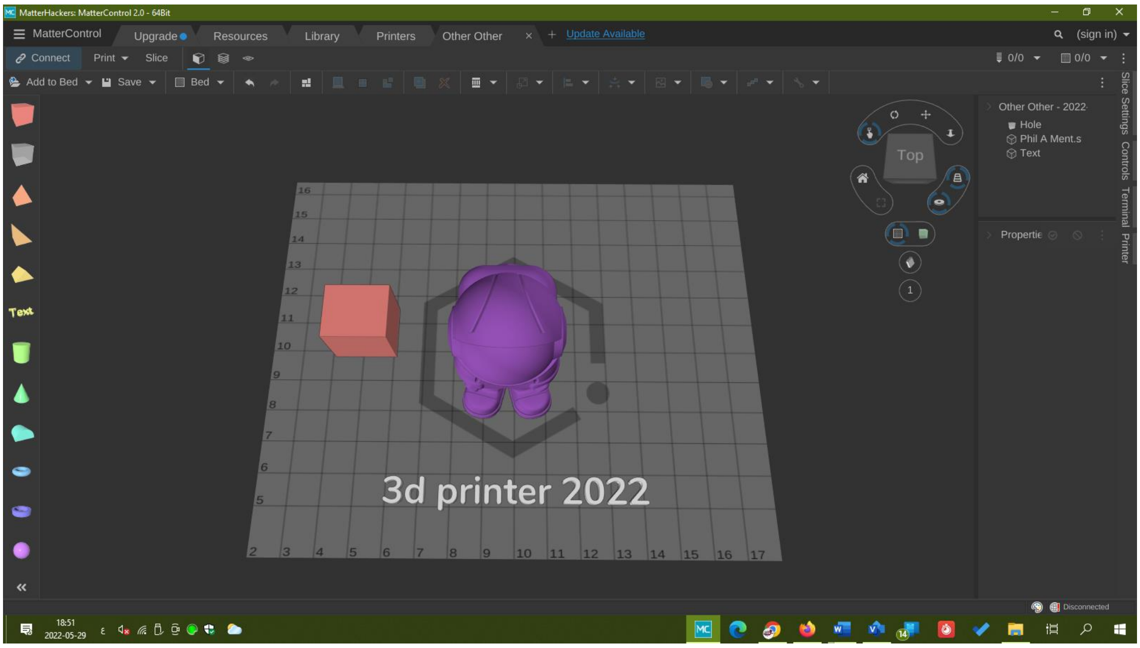


Figure III.42; MatterControl software interface

III.4.4. Interface software

This kind of software can send the G-code directly to the printer and control its process.

III.4.4.1. Pronterface

III.4.4.1.1. Overview

Pronterface is a 3D printing host software suite, that talks to your printer and handles the printing process by connecting the printer with the computer platform that the Pronterface installs in, also Pronterface can be used on many platforms like Windows and Linux. [82]

Figure III.43: Pronterface logo

III.4.4.1.2. The general structure of the program

The overall structure of the program has a slightly complex interface, which in turn consists of a menu, toolbar, X Y Z axis control area, print speed and flow space 3d object preview, the message area of the current actions, and message display console compilation.

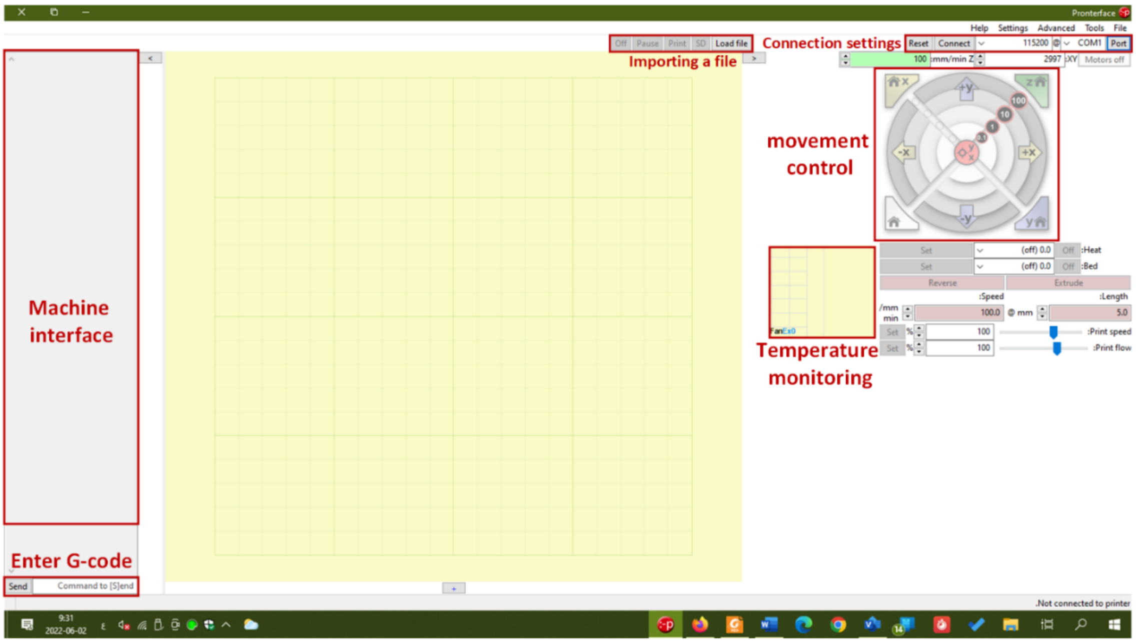


Figure III.44: Pronterface software interface

III.5. Conclusion

In this chapter, we presented most of the basic components of our printer and we knew an overview of it and its characteristics, as well we saw its true images and 3D representations.

So, in the next chapter, all these components and parts will come together to be our printer.

Chapter IV: Realization Of The 3D Printer

IV.1. Introduction

In this chapter, we will realize the 3D printer concept that we have designed beforehand in fact, but we cannot put the components without recognizing the printer design and the mechanism of its work, and that is what we will address. Then we will assemble the step-by-step printer according to our design. At last, we discuss the results obtained, and what we want to develop in the near future.

IV.2. The général mécanisme

As we said earlier, we chose for our project to achieve an FDM 3D printer with a Cartesian movement, and she is of the type (Cartesian-XZ-head).

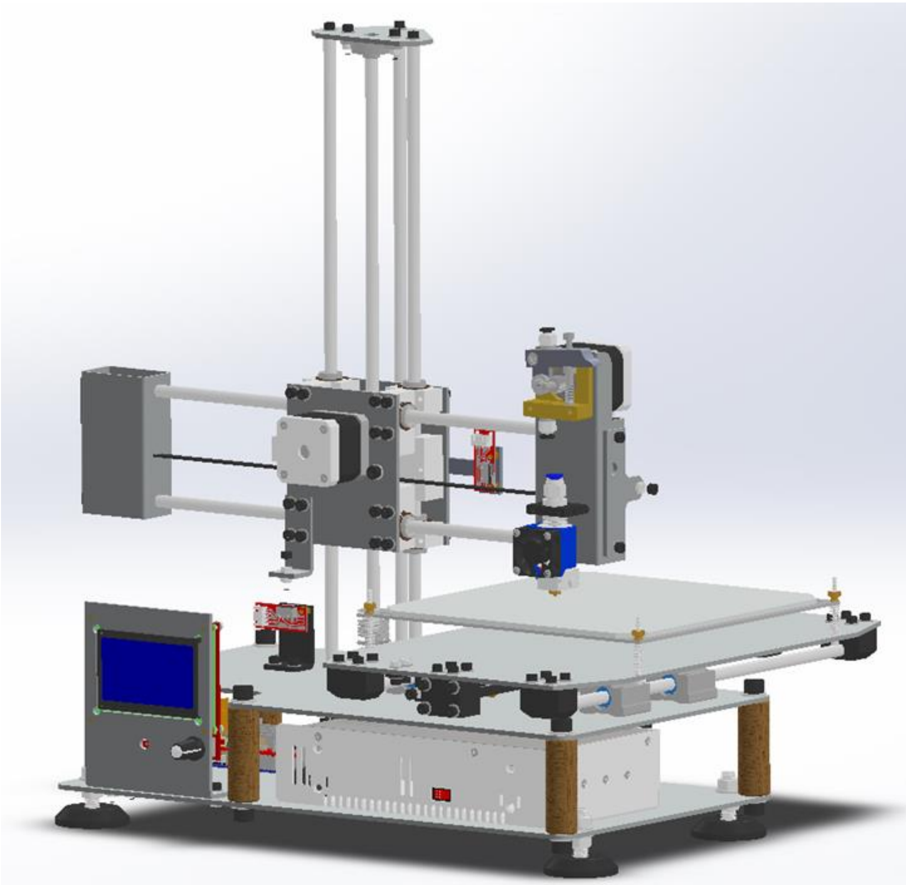


Figure IV.1: 3D model of the 3d printer

So, our printer will consist of three axes, the X axis that connected to the printing head and allow it to move horizontally along the axis, the Z axis which holds the X axis and allows the printing head to move vertically at the height of the axis, and finally the Y axis represented by the printing bed which allows the movement of the model horizontally during printing along the axis.

IV.2.1. The X axis

The X axis ensures the movement of the extrusion nozzle on the horizontal plane.

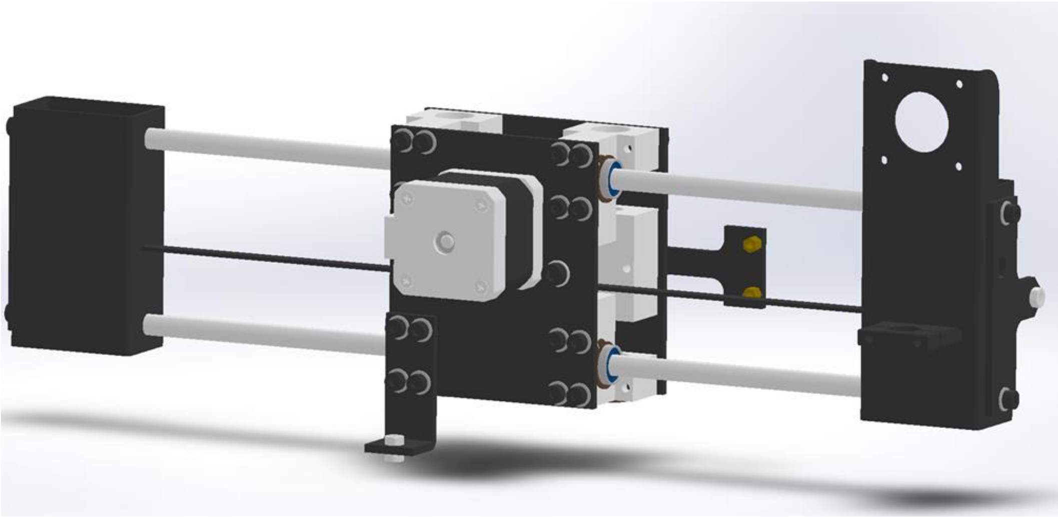


Figure IV.2: The design of horizontal X-axis

IV.2.1.1. Motion transmission

we're going to need one stepper motor to move the X-axis, and it's going to be connected to the it moving part of the X axis, creating a rotational movement.

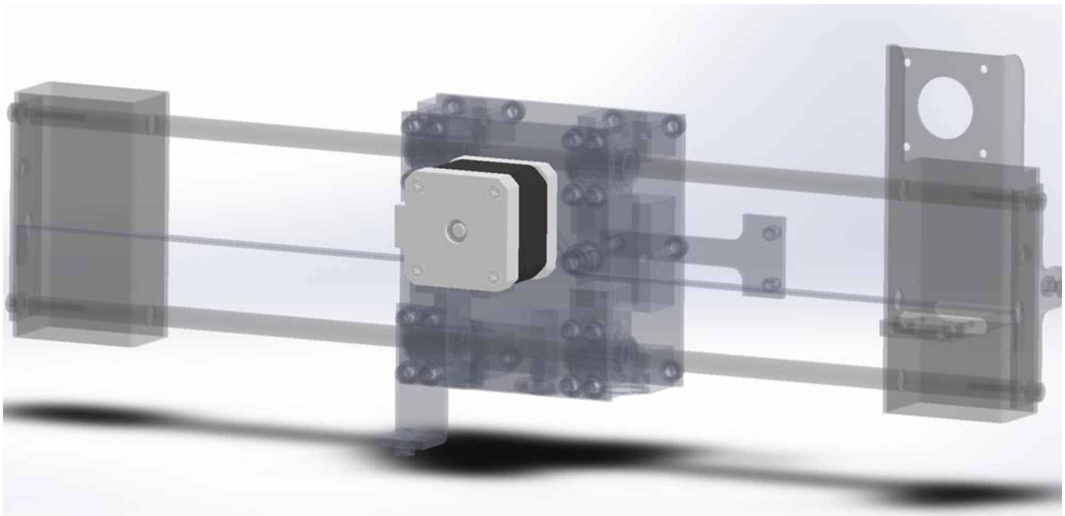


Figure IV.3: The X axis stepper motor

IV.2.1.2. Motion transformation

The movement provided by the stepper motor is rotational and we need linear movement to move the X axis horizontally so we will turn this movement through a Timing belt/ pulley system, so that the timing belt is connected to the two sides of the axis and connected to the stepper motor by a pulley.

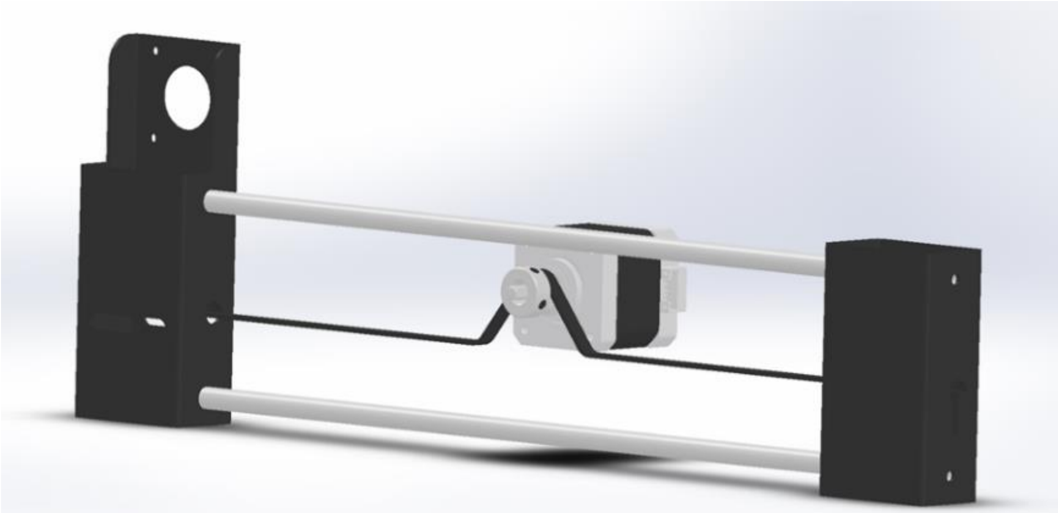


Figure IV.4: The X axis Motion transformation

IV.2.2. The Y axis

The Y axis ensures the movement of the print bed on the horizontal plane.

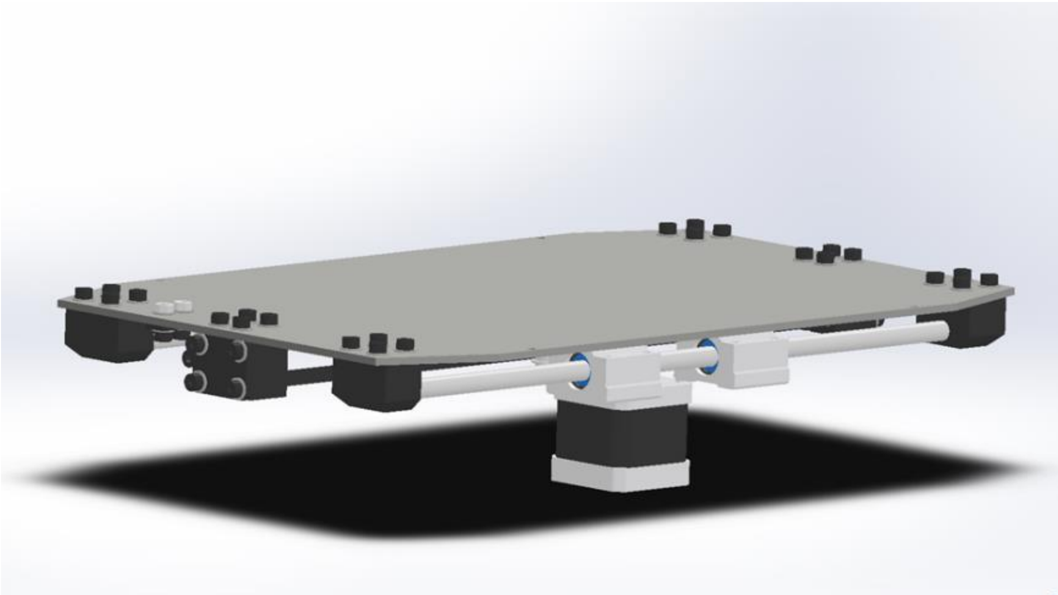


Figure IV.5: The design of horizontal Y axis

IV.2.2.1. Motion transmission

We'll also use an engine in this axis, but it'll be connected to the base of the printer where the axis is fixed, and the engine axis will be parallel to the smooth rails with the direction of the movement.

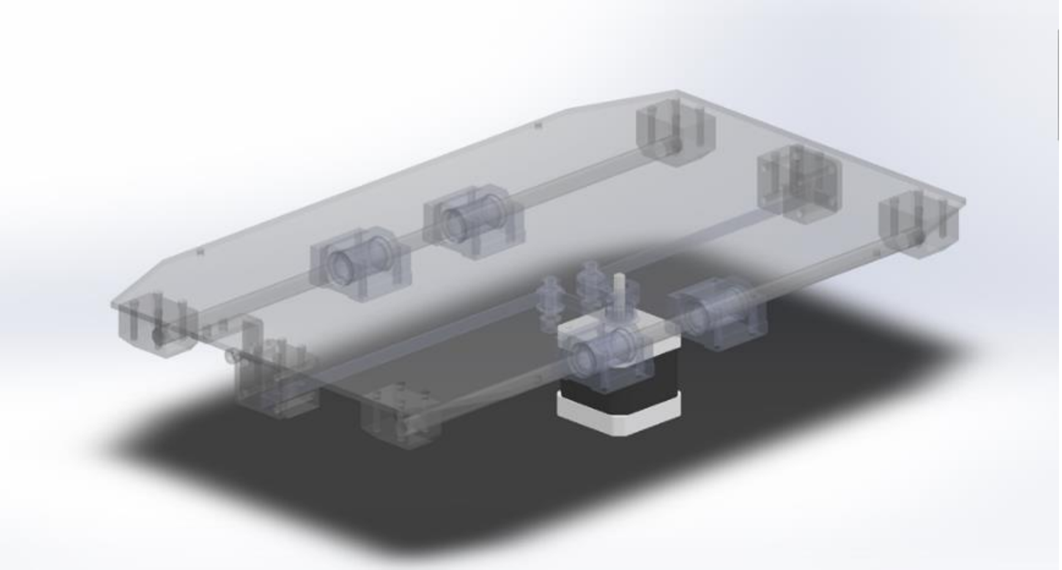


Figure IV.6: The Y axis stepper motor

IV.2.2.2. Motion transformation

The x-axis adopts a movement similar to the axis that we use a timing belt/pulley system to shift the movement.

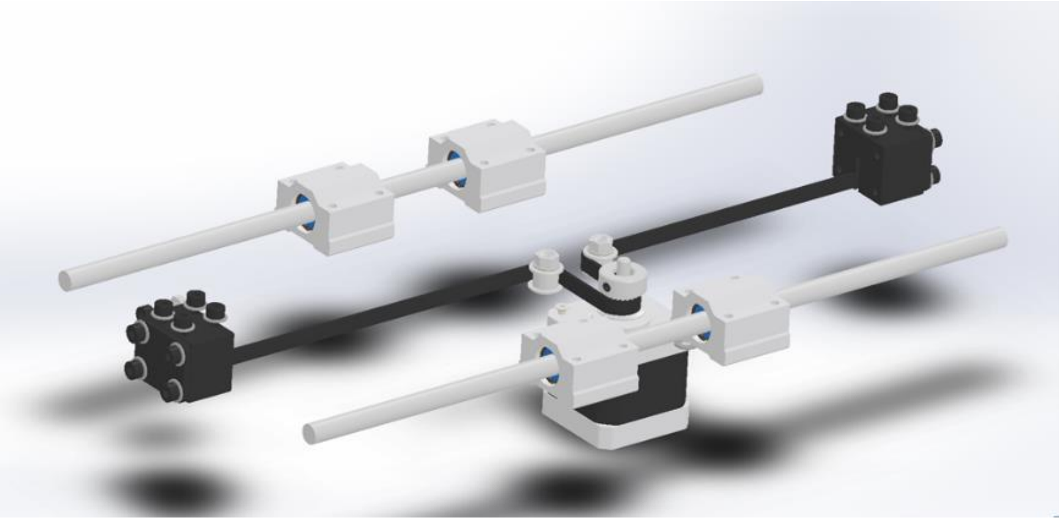


Figure IV.7: The Y axis Motion transformation

IV.2.3. The Z axis

The Z axis ensures the movement of the print bed on the horizontal plane.

Figure IV.8: The Z axis

IV.2.3.1. Motion transmission

Similar to the Y axis stepper motor, we need one stepper motor to move the Z axis, and it will be connected to the stator of the printer in order to provide a vertical rotational movement.

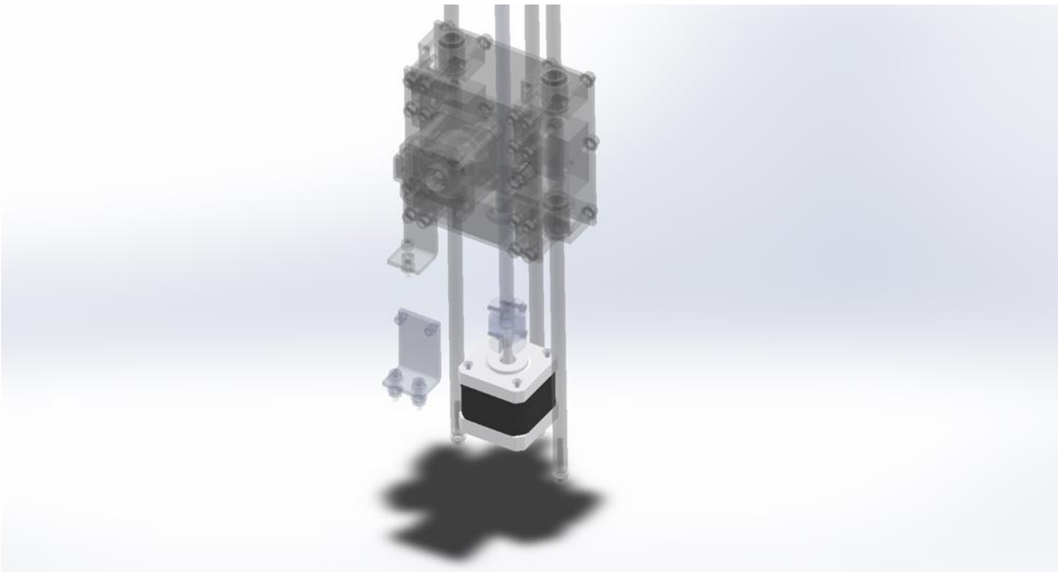


Figure IV.9: The Z axis stepper motor

IV.2.3.2. Motion transmission

To convert the rotational motion to a vertical linear motion, we will helical connection to the axis of the stepper motor by a coupler, and this helix is perpendicular to the Y axis and connected to the stator of the printer.

Figure IV.10: The Z axis motion transformation

IV.3. Assembly tools

Fortunately, building a 3D printer does not require a well-stocked shop, but we need tools for cutting, drilling, welding and electrical measurement, so below are some of the tools we need.

Figure IV.11: Some tools used to assemble the printer

IV.4. Assembly the 3d printer

First of all, the firmware must be installed with all its parts, but first some parts must be provided, including 3D-printed parts, some wooden parts, also we need some aluminum plates prepared with specific dimensions.

- **Step 1:** we begin to put the bottom plate of the base and install the plastic legs in the four corners with screws and then install the power supply on the bottom plate of the base.

Figure IV.12: The bottom of the base

- **Step 2: b**elow the upper plate of the base, we install the stepper motors of the axis Z and the Y axis as a thick so that the stepper motor block on the interior and the stepper motor axis cross the plate to stand out from the top of the plate ،and on the upper plate of the base we install the linear bearing holder for the Y axes.

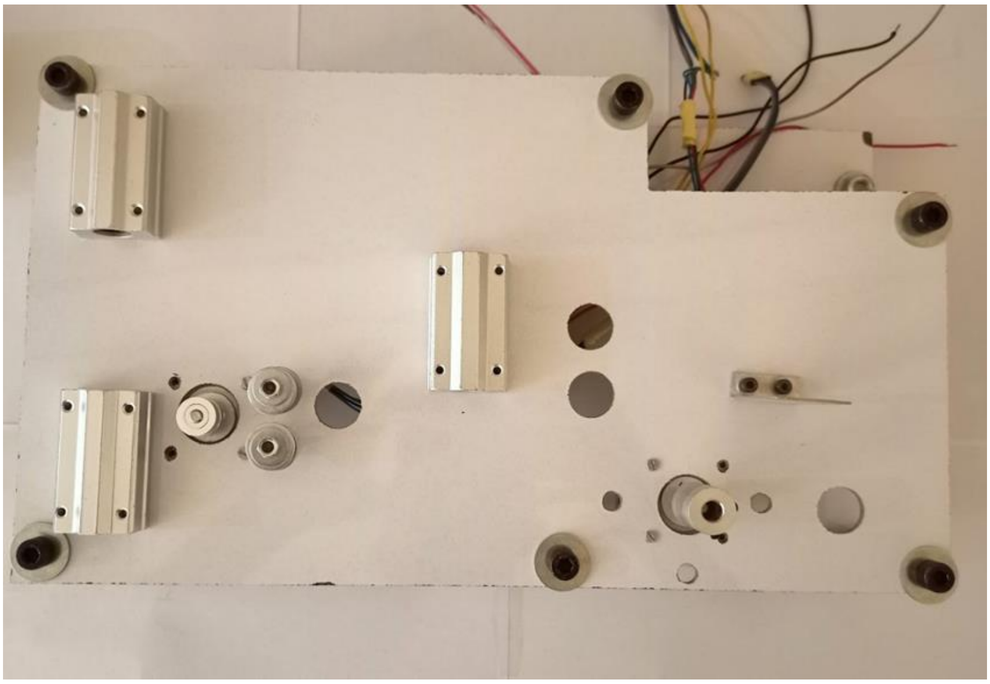


Figure IV.13: The Top of the base

- **Step 3: w**e bring hollow, pre-prepared wooden rods and install the upper and lower base plates.

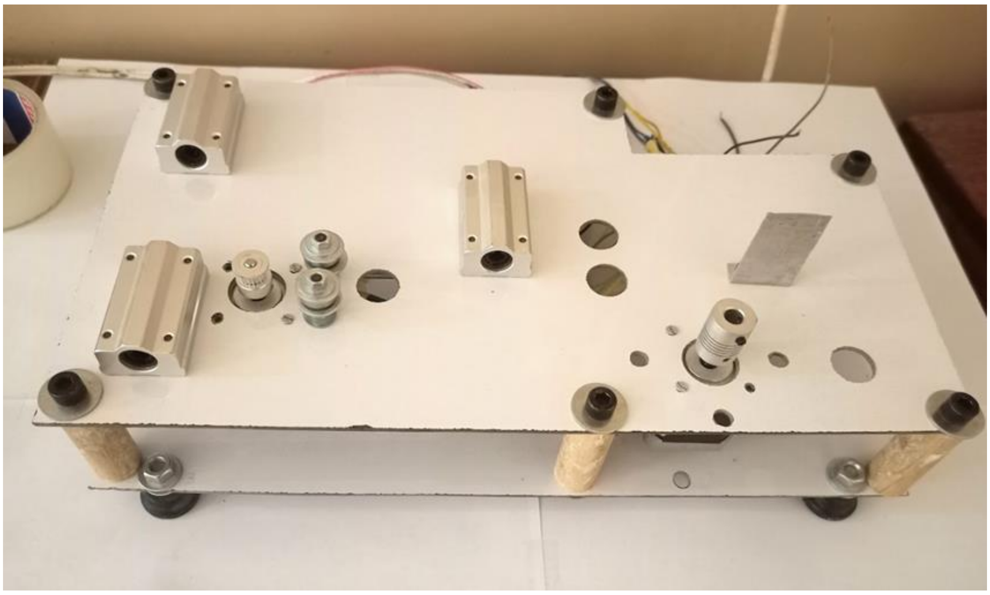


Figure IV.14: The final look of the base

- **Step 4:** we build the Y axis with all its components, and then connect it with the top plate to the base by passing linear rods through the linear bearings.

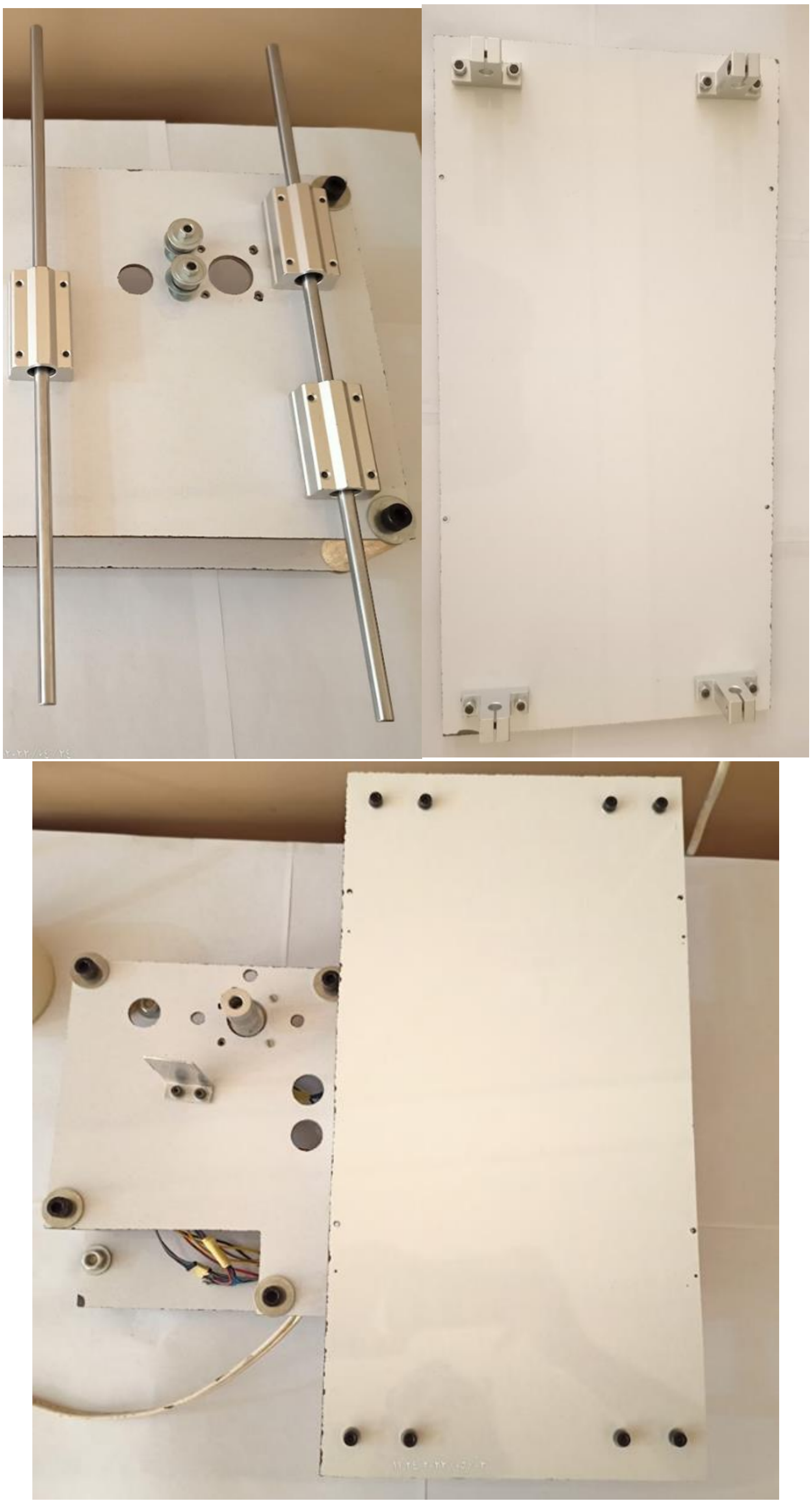


Figure IV.15: Top view of the Y axis after it is installed on the base of the printer

- **Step 5:** we install the linear rods of the Z axis and the X axis on the 3D printed stand using four linear bearings and then install it on the upper plate of the base using aluminum pieces from the upper and lower end of the axis.

Figure IV.16: top view of the X axis movement components assembled

- **Step 6:** after that we connect the leadscrew to the Z axis stepper motor using a coupler, and then pass the leadscrew nut that we connect to the X axis holder, then on the X axis holder we install the stepper motor using a square aluminum piece and then install two pieces of aluminum on both sides of the X axis to lock the two linear rods on parallel, and on the internal end of the X axis we install the printing head, the extruder and the extruder stepper motor as described below.

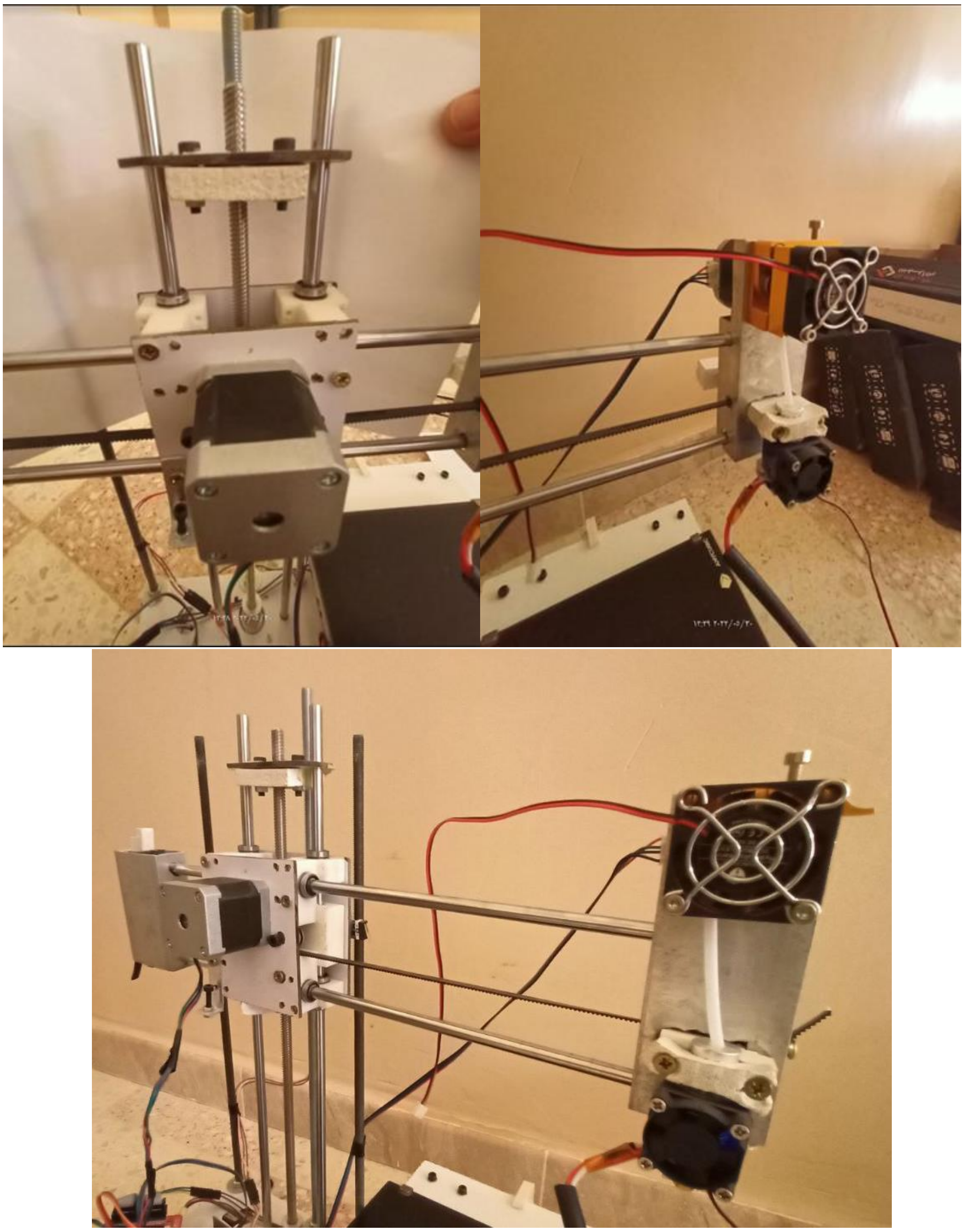


Figure IV.17: The final look of the X axis and Z axis

- **Step 7:** we install the remaining components, which are the limit switches, the timing belts, the Arduino/Ramps board, and the printing bed.

- **Step 8:** because of the over weight of the X axis on the Z axis, we switch the small screws passing through the wooden bars of the base with threaded rods, and at the end of which we install an aluminum plate so that we fix the end of the Z axis with the threaded rods to ensure the stability of the Z axis during printing.

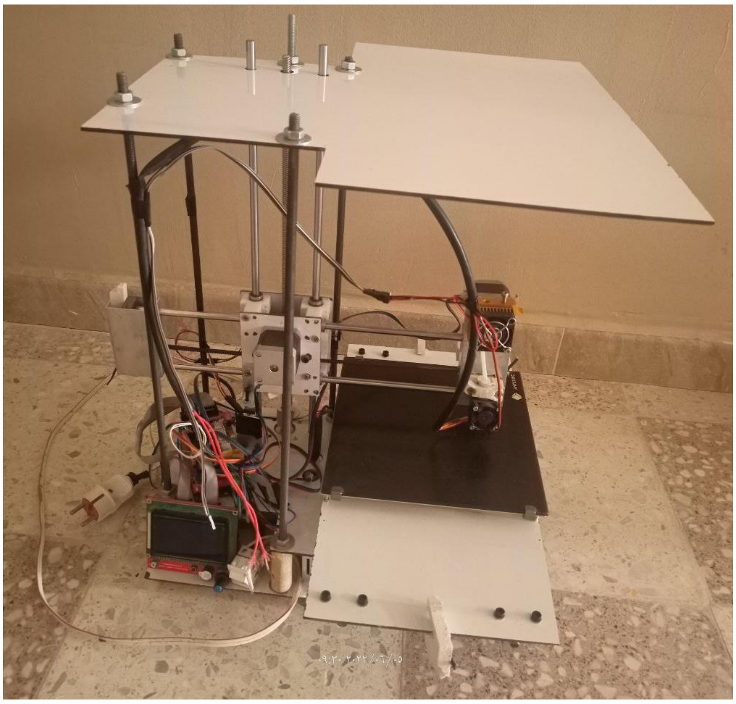


Figure IV.18: The final look of the 3D printer

IV.5. Electrical diagram

After the installation of all the parts and components, now we need to connect the electrical connections as shown in the figure below.

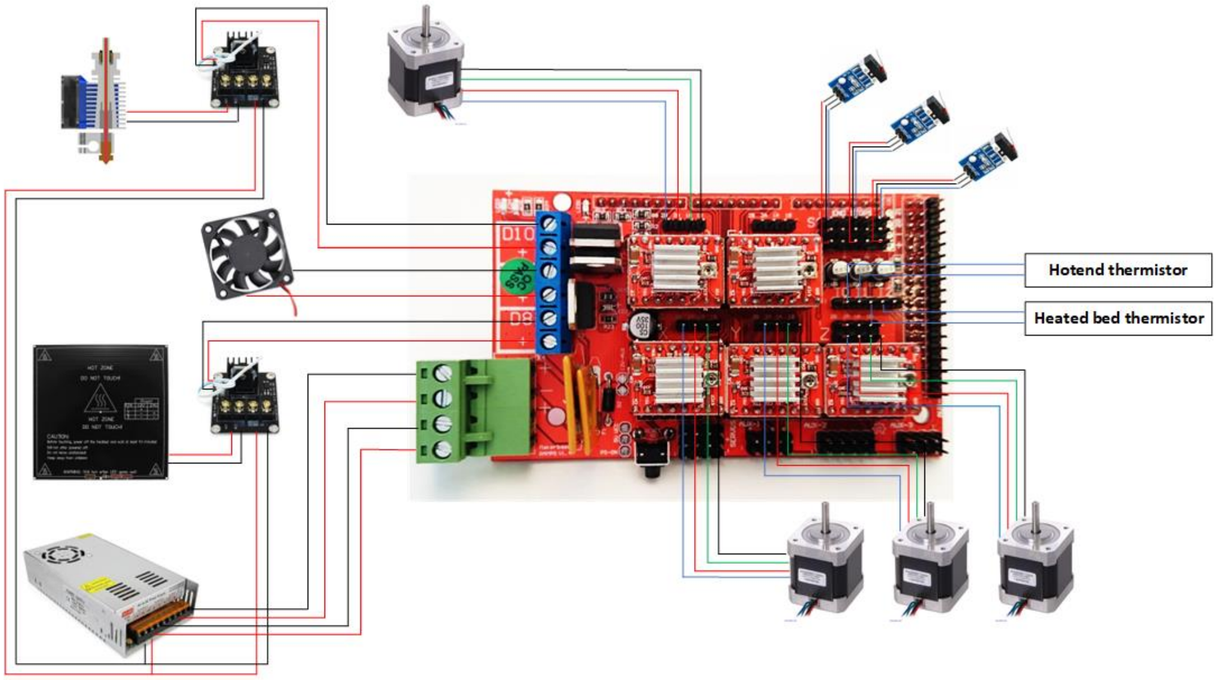


Figure IV.19: Wiring of the 3D printer electronic components

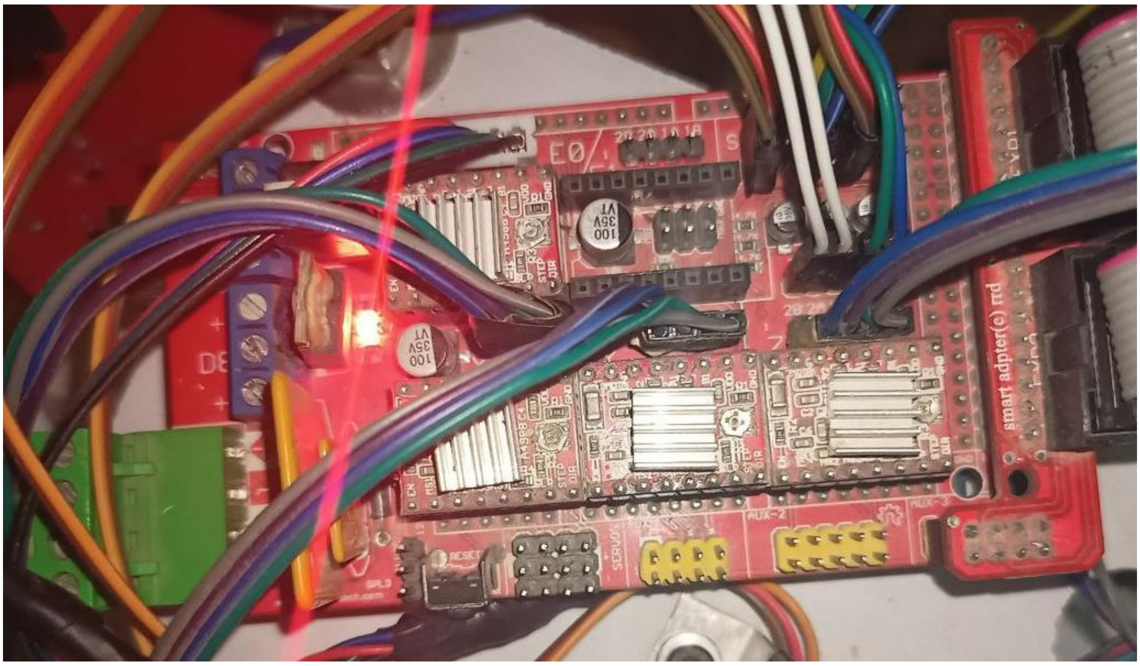


Figure IV.20: Electrical diagram of the 3d printer

IV.6. Printing test

IV.6.1. Calibration

Before attempting the first print, it is necessary to properly calibrate the printer. Skipping this step or rushing will lead to frustration and failure to print, so it's important that we take the time to ensure the device is properly calibrated.

Each device may have its own calibration procedure, but there are key points to check:

- The chassis is stable and properly aligned.
- The belts are tight.
- The bed is level with the extruder track.
- The wick wicks freely from the spool, without causing much tension on the extruder.
- The stepper motors current is set correctly.
- The firmware settings are correct, including: speeds and acceleration of the axis of movement; temperature control; Limit switches direction of rotation of the motors.
- The extruder is calibrated in the firmware with the correct number of steps per mm of the filament. The number of steps per mm of the extruder is necessary. Cura expects the machine to produce exactly the exact amount of filament.

IV.6.2. Practical steps for carrying out the experiment

- **Step 1:** To print our first model, we first run Solidworks and create a 2cm cube, and after completion, we save the model as stl. Or we use the easiest way, which is to download a ready-made template in .stl format from the Thingiverse website, so we search for “Test 3d printer” and choose a simple template to try.

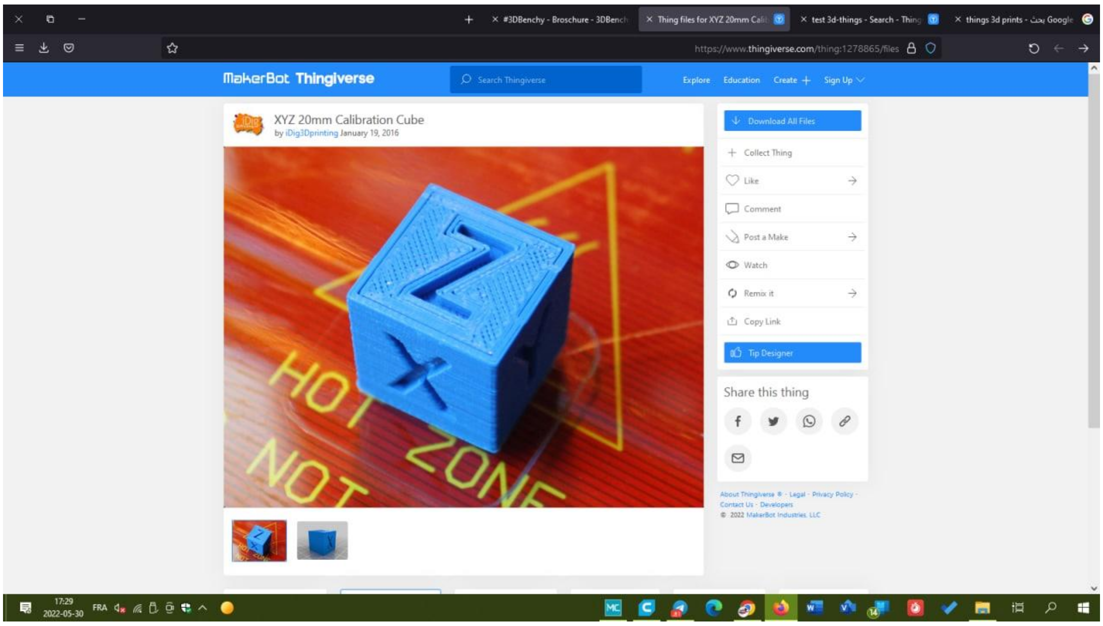


Figure IV.21: Download a print-ready template from Thingiverse

- **Step 2:** We move to cura software, and create a new configuration.

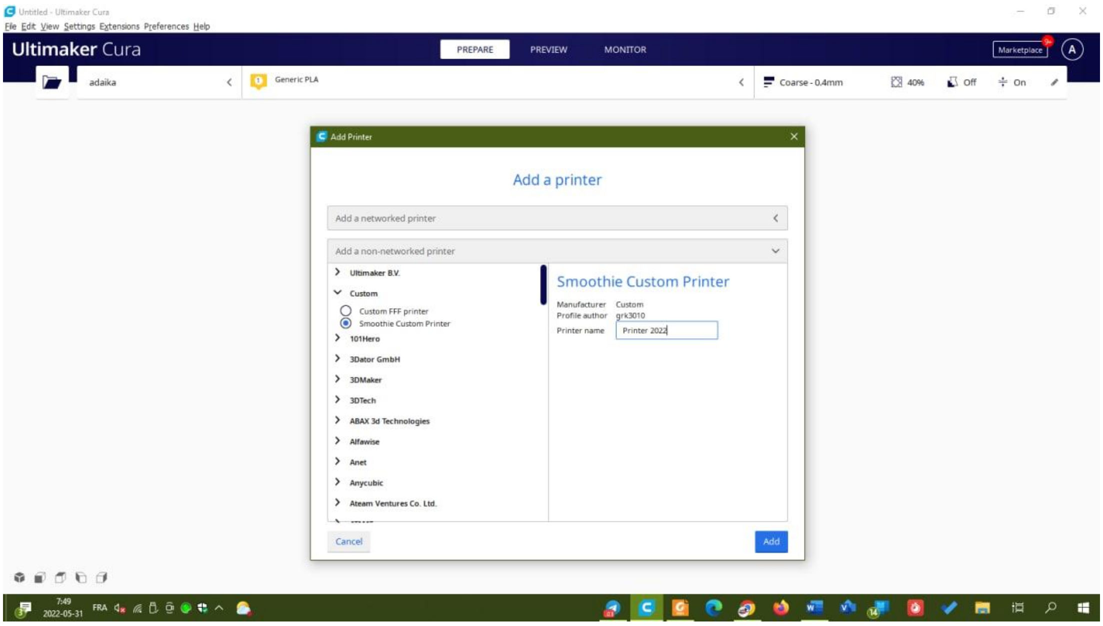


Figure IV.22: The start configuration

- **Step 3:** The third step: We open the print settings and change them, taking into account the characteristics of our printer, as shown in the figure IV.23

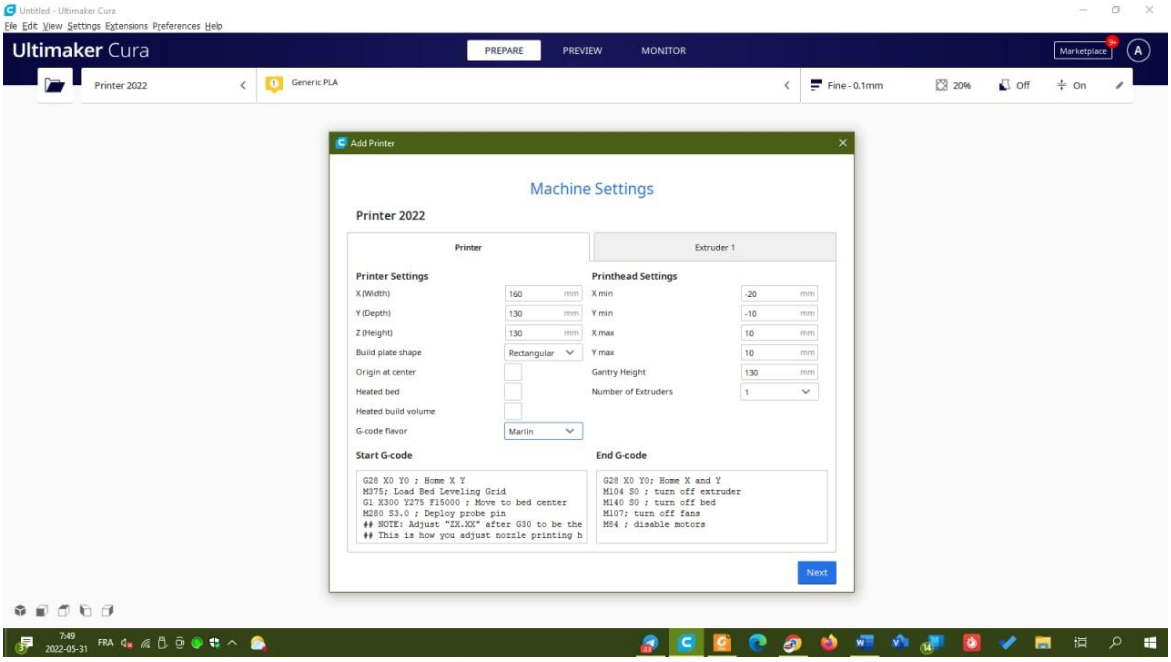


Figure IV.23: Change in printer dimensions

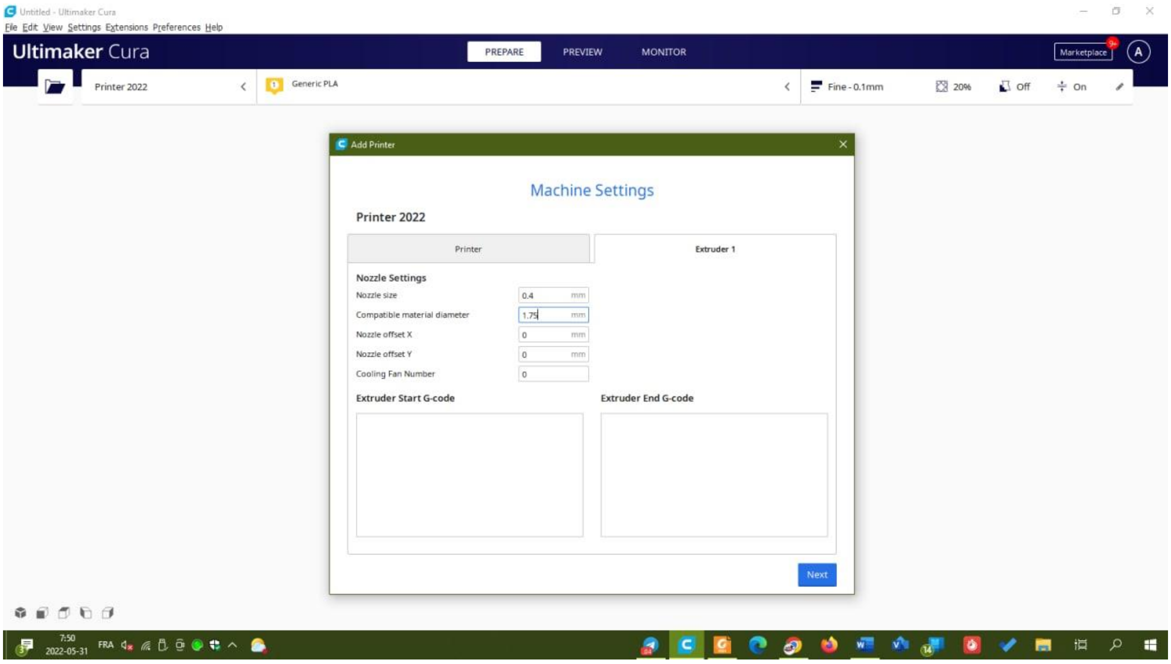


Figure IV.24: change in nozzle size and compatible material diameter

- **Step 4:** Then open the .stl format model.

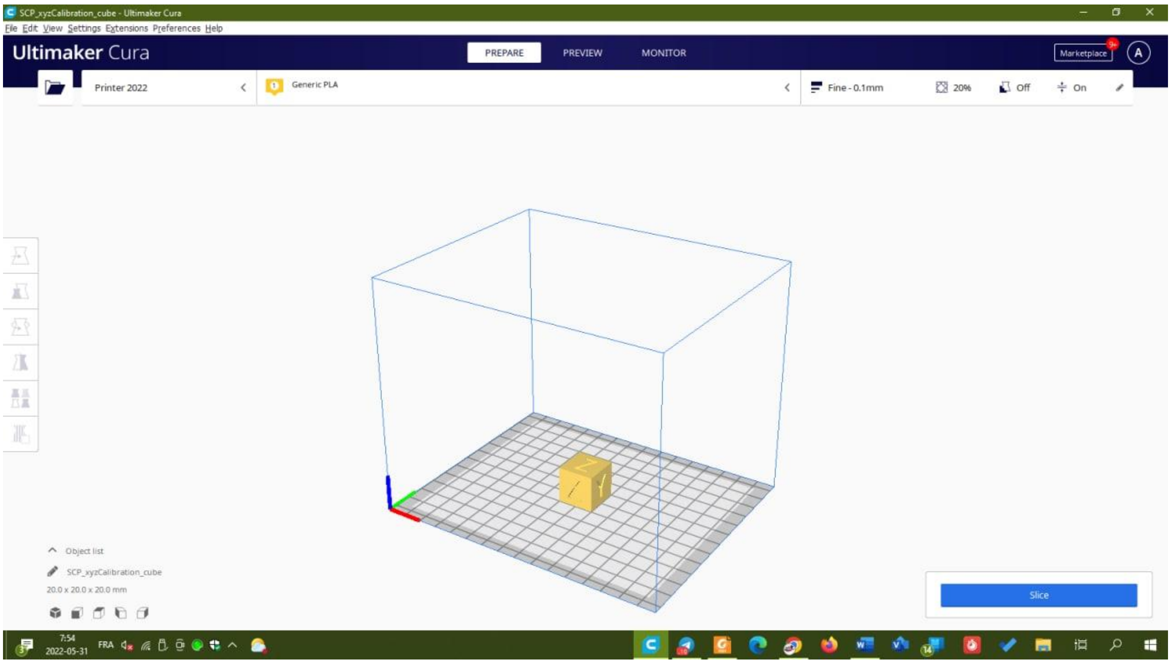


Figure IV.25: Slicing the 3d model using Cura

- **Step 5:** G-code file export. But before that, we can set 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. We have set the layer height for all layers to be 0.4mm which is the same as the nozzle diameter.
  - ✓ **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 inuence print weight, material usage, strength, print time and sometimes decorative properties. We have set the infill percentage to be only 40% , this will result the inner volume of the printed object to be 60% hollow.

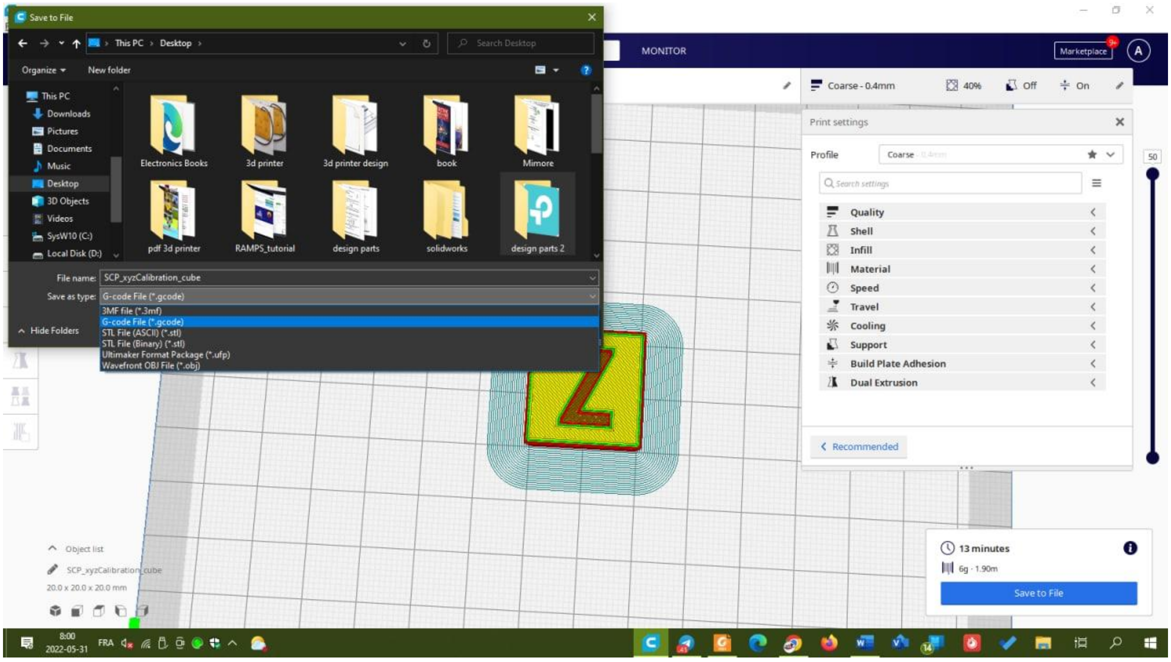


Figure IV.26: Convert model to G-code format

- **Step 6:** After exporting the model from the Cura software, we now open this exported file in the prontaerface program to create motion paths for each layer of the 3D model so that we can export it as a G-code file.

To send the G-code module to the printer for printing, there are two ways:

1. First method, we copy the file to an SD card and connect it to the LCD controller.
2. As for the second method, we open the prontaerface interface and then connect the printer to the computer through the USB port on the Arduino board, and through the prontaerface interface we choose the appropriate socket.

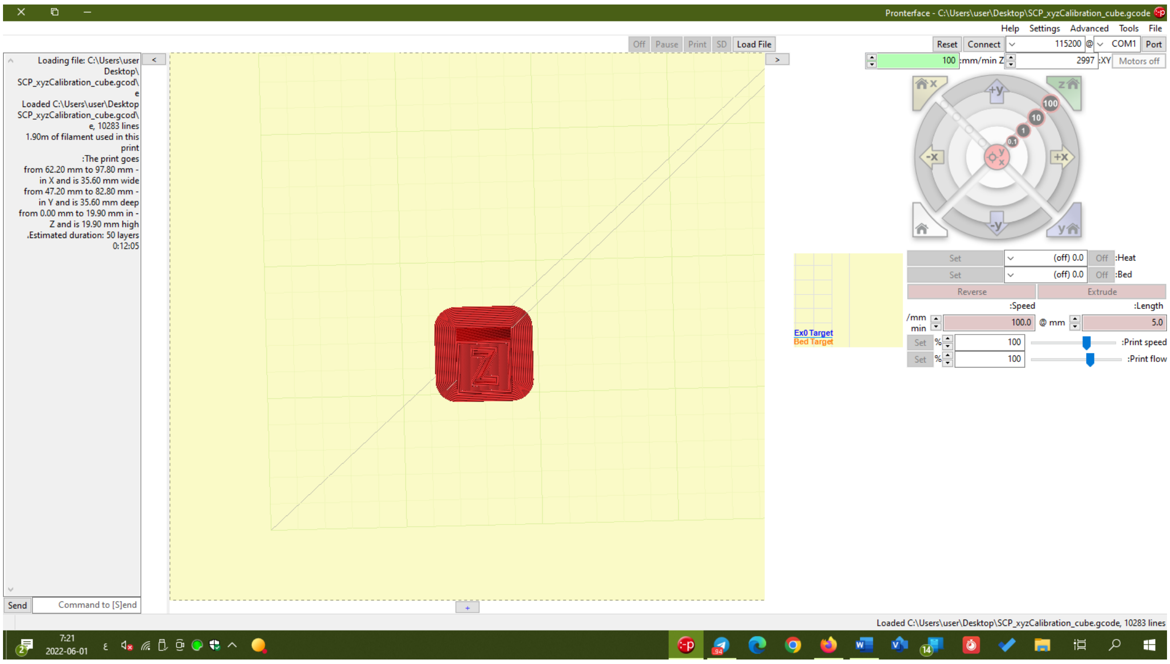


Figure IV.27: Import the model in G-Code format to Pronterface

- **Step 7:** Nous entrons la vitesse de connexion dans le débit en bauds, qui est de 250 000, et le port série est COM4. et appuyez sur connecter

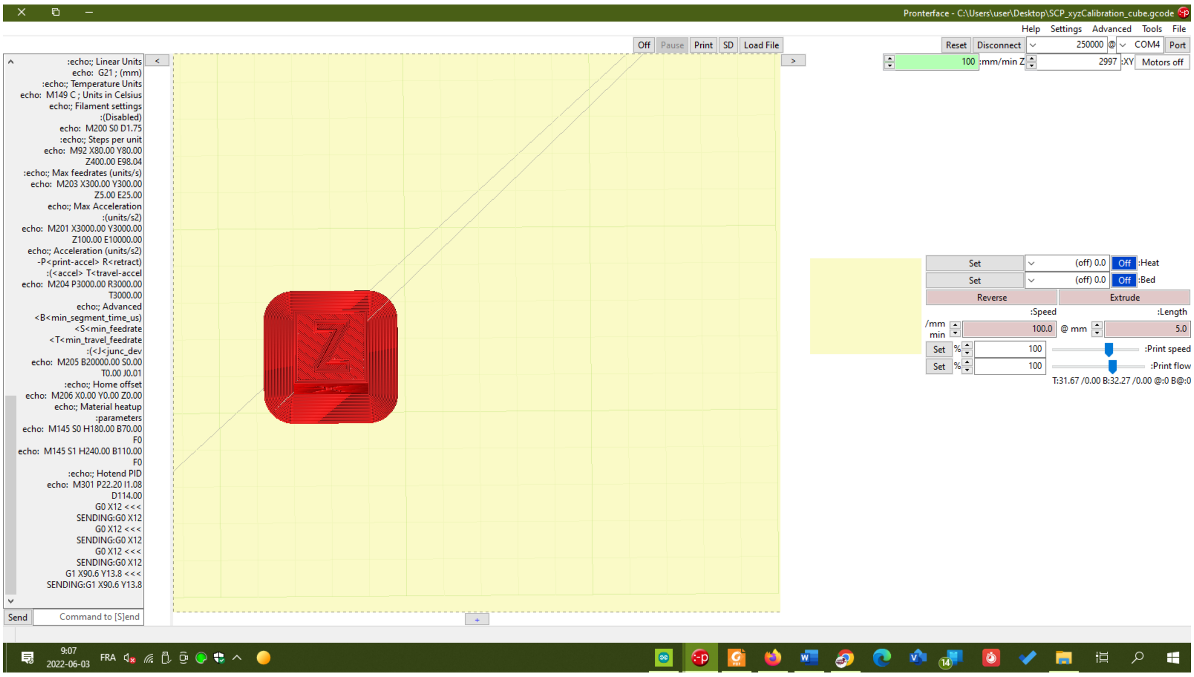


Figure IV.28: Connect with Pronterface software

- **Step 8:** From a side view, we noticed a slight slope of the base as shown in Figure 4.21, and this inclination is caused by several factors that may lead to the impossibility of the printing process or the low quality of the product. The surface must be perfectly flat so that the first printing layer adheres perfectly.

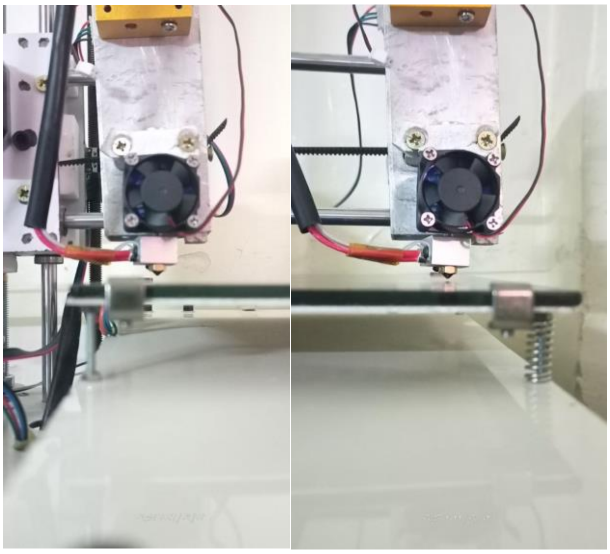


Figure IV.29: Tilted printing base side view

- **Step 9:**

Before starting the 3D Printing process, the printing head travels to X0 and Y0 and Z0 position, generally this position is referenced to as "home", Figure IV.29 shows the 3D Printing head after moving to X0 and Y0 and Z0 position.

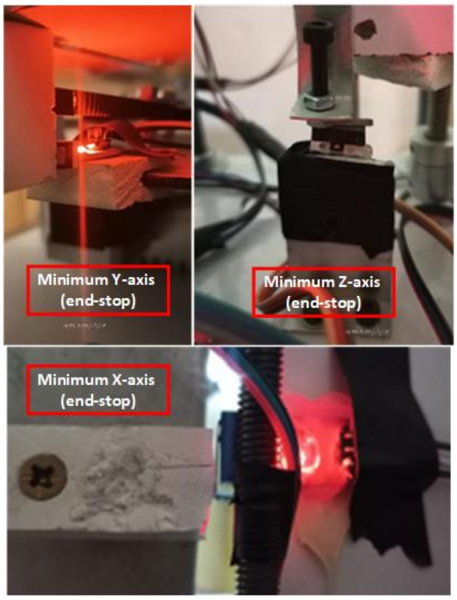


Figure IV.30: End-stops indicating home position at X0 Y0 Z0

- **Step 10:** After determining the initial point of the 3D printer head, we are ready to start the stereoscopic print that we previously downloaded the file for the remaining step by pressing the Print button in the prontaerface program.

- **Step 11:** After that, the printing head temperature increases until it reaches its reference temperature, notice in Figure 4.42 the reference temperature is 170°.

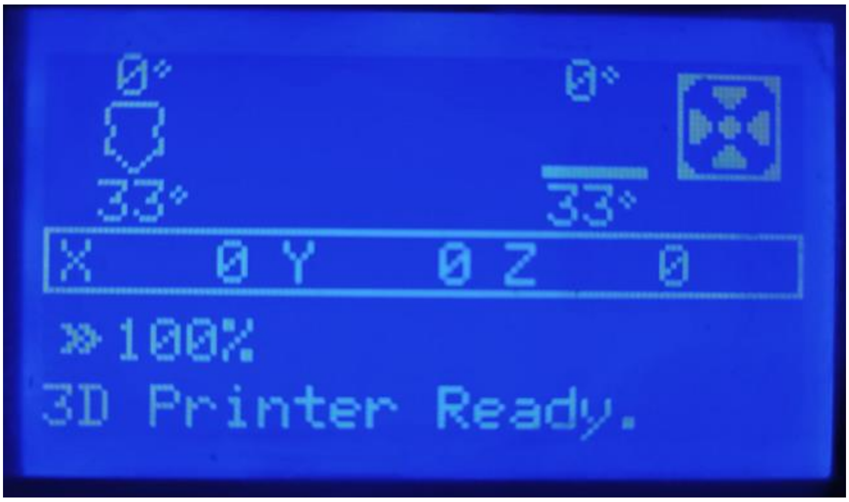


Figure IV.31: 3D printer LCD screen in operation

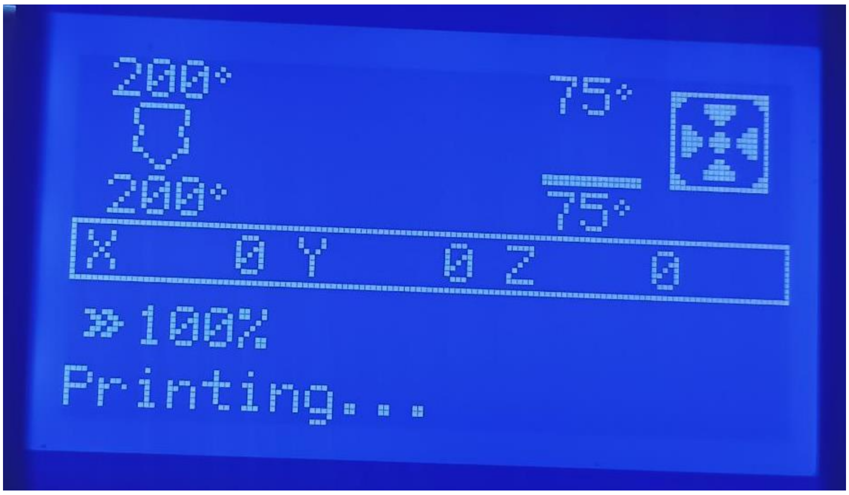


Figure IV.32: Heating the printing head

IV.7. Suggestions for improving the machine

Our printer needs so many improvements that we couldn't do it due to lack of time and money, and most importantly the difficulty of getting some basic equipment. We mention them:

- Using the structure of the printer in order to protect it in addition to reducing vibrations.
- The change of driver motor with another type more powerful.
- Modification of the mechanical structure of the printer by adding another stepper motor to the Z axis in order to reduce vibrations.
- Changing the mechanism of the print head system with a system that accepts changing tools and tasks.
- We improve the control panel by replacing the RAMPS 1.4 with another control panel, preferably one that supports Wi-Fi technology.
- Adding other extrusion heads so we can print in multiple colours.
- We improve the software part by adding wireless printing function, adding compatibility with other tools (laser cutting, milling, etc.)

IV.8. Cost of Project

Table 21- Cost electrical and electronic parts

Electrical and Electronic parts						
Control parts	RAMPS 1.4 Kit + Mega 2560 + 5pcs A4988 + LCD 12864 Display For 3D Printer RepRap	11 200,00 DA	Ordered: 1		11 200,00 DA	https://www.websoog.com/
	XD-206 crash switch module microcontroller module robot collision sent the DuPont line	400,00 DA	Ordered: 3		1200,00 DA	https://www.websoog.com/
Power parts	12V 30A DC Power supply for CCTV LED Robotics DIY Projects	2 730,00 DA	Ordered: 1		2730,00 DA	https://www.websoog.com/
	module d'alimentation d'imprimante 3d	1 500,00 DA	Ordered: 2		3000,00 DA	https://powertech-dz.net/

Table 22- Cost Electromechanic part

Electromechanic part						
Stepper motor	NEMA 17 42HS40 1.7A	2 950,00 DA	Ordered: 3		8 850,00 DA	https://www.websoog.com/

Table 23- Cost heating and melting parts

Heating and Melting Parts						
Printing Head	E3D V6 Jhead	1 900,00 DA	Ordered: 2		3 800,00 DA	https://www.websoog.com/
Printing Head	Extrudeuse contrôle E3D V6 1.75MM/0.6M	2 500,00 DA	Ordered: 1		2 500,00 DA	https://powertech-dz.net/
Heated bed	HOTBED + GLASS (220 x 240mm Orange	7 000,00 DA	Ordered: 1		7 000,00 DA	https://www.websoog.com/
Filament (PLA)	PLA FILAMENT Normal 1,75mm 1Kg **Couleur de produit Sky Blue**	4 500,00 DA	Ordered: 1		4 500,00 DA	https://www.websoog.com/
Nozzle	3D Nozzle For 1.75mm MK8 Makerbot 0,2mm /5mm	150,00 DA	Ordered: 1		150,00 DA	https://www.websoog.com/
3D printer Leveling	3D printer Leveling compo-nents M3 screw Leveling spring	600,00 DA	Ordered: 4		2 400,00 DA	https://www.websoog.com/

Table 24- Cost mechanical parts

Mechanical parts						
Extruder	3D Printer Head MK8 Extruder J-head Hotend Nozzle 0.4mm Feed Inlet Diameter 1.75 Filament Extra Nozzle	6 500,00 DA	Ordered: 1		6 500,00 DA	https://www.websoog.com/
Transmissions	3D printer spares 2GT-6mm.Rubber opening syn-chronous belt	600,00 DA	Ordered: 1		600,00 DA	https://www.websoog.com/
	GT2 Timing Pulley 20teeth Alumium Bore 5mm for width 6mm belt	350,00 DA	Ordered: 3		1 050,00 DA	https://www.websoog.com/
	Vertical 8mm Ball Bearing Slide Bushing Linear Shaft Optical Axis 500mm	1 100,00 DA	Ordered: 2		2 200,00 DA	https://www.websoog.com/
	Vertical 8mm Ball Bearing Slide Bushing Linear Shaft Optical Axis 400mm	1 000,00 DA	Ordered: 4		4 000,00 DA	https://www.websoog.com/
	Aluminum Couplers for step-per motor 5 5mm 5*8mm 8*8mm **(Size 5*8)**	900,00 DA	Ordered: 1		900,00 DA	https://www.websoog.com/
	8mm Acme threaded Rod Stainless steel Leadscrew+T8 Nut 500mm	2 100,00 DA	Ordered: 1		2 100,00 DA	https://www.websoog.com/
	LM8UU Linear Ball Bearing	350,00 DA	Ordered: 8		2 800,00 DA	https://www.websoog.com/
	SK8 8mm Linear Bearing Rail Shaft Support Linear Rail Vertical Bearings Shaft Guide Support Bracket	370,00 DA	Ordered: 8		2 960,00 DA	https://www.websoog.com/
	SC8UU Linear Ball Bearing XYZ Table CNC Router	550,00 DA	Ordered: 8		4 400,00 DA	https://www.websoog.com/

Table 25- Other tools cost

Other tools						
jumper wires	30cm Male TO Female 40Pin Solderless Jumper Breadboard Wires	400,00 DA	Ordered: 1		400 DA	https://www.websoog.com/
	30cm Male TO Male 40Pin Solderless Jumper Breadboard Wires	400,00 DA	Ordered: 2		800 DA	https://www.websoog.com/
Tools	Other tools for the printer body	16000 DA	Ordered: Lots	No pictures	16 000,00 DA	Several sources in the city of El Oued

Table 26- Total amount

Total amount	**92 040,00 DA**

IV.9. Resultants and discussion

Before discussing the results, it is important to mention that the achievement of a digitally controlled 3D printer added great scientific value to us in electronics, programming, G code creation, design and mechanical manufacturing and gave us a lot of experience on the engineer's work in the professional field where it allowed us to devote our studies in the field of electrical control. This is all within the framework of the end-of-study project.

Once the realization was finished, we went to the tests. The results obtained are very satisfactory, the printer operates in series motion and precision.

We did the hardest part of the project and it's precise motion configuration according to the 3D model sent to the printer.

In order to print the first three-dimensional model, we will need to heat Heated bed at an appropriate temperature, requiring the availability of mosfet to bear the required temperature such as "NCEP01T18T Heated bed MOSFET PCB" and are available to us but unfortunately did not operate.

IV.10. Conclusion

In this chapter, we designed and assembled a full 3D printer based on the devices mentioned in the previous chapter and then discussed the results obtained. Our tests showed satisfactory results.

General Conclusion

3D printing revolutionizes today's printing world, as it allows the product to form layer by layer, with plenty of material available

The power of 3D printing, on conventional manufacturing techniques, is that it allows you to create new and more complex forms of things that can be better customized and improved.

If 3D printing continues to expand, it is supposed to lead to major industrial, economic and commercial changes. Because 3D printing is more suitable for local production, thus most people become 3D printer holders (such as TV), leading to the collapse of the entire usual production chain, with many intermediaries (manufacturers, distributors, carriers, warehouses, distributors). Individuals will become creative and direct producers of the things that surround them. 3D printing will bring us to a world where mass production is replaced by locally made objects at the request of the end user.

In this work, we designed and implemented a prototype 3D printer based on fused filament fabrication (FFF) technology. During the implementation of the project, we really enjoyed the work and were able to gain more ideas at the theoretical or practical level.

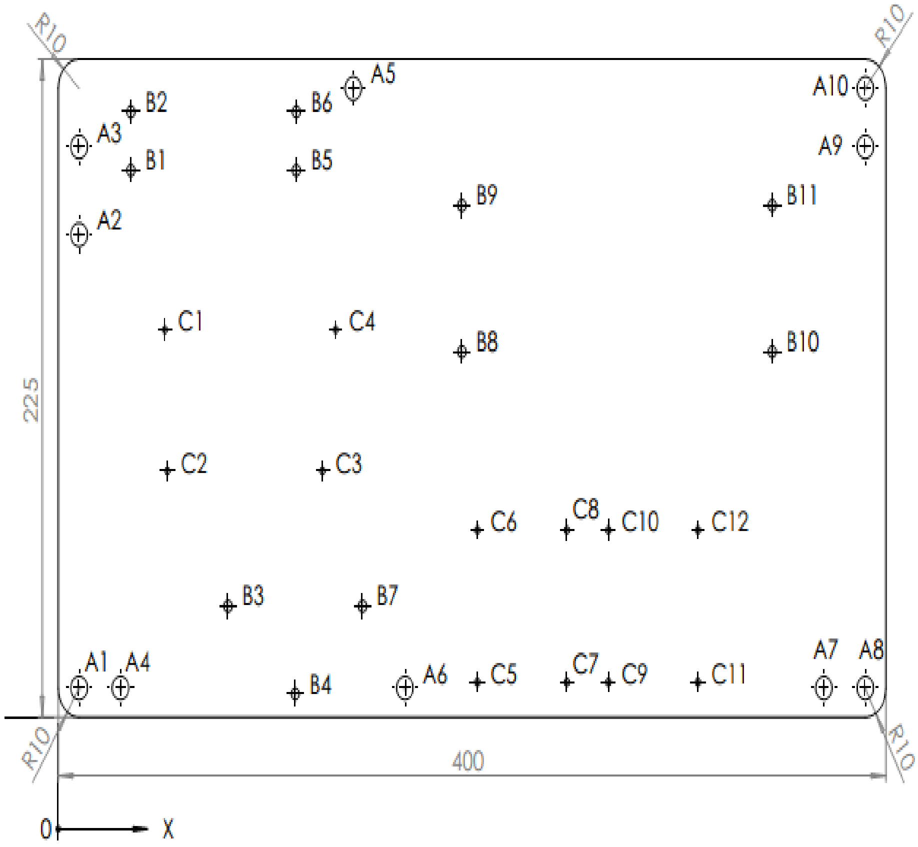
For this reason, we half build a 3D printer step by step, including: study current types of 3D printers, study electronic and mechanical hardware and software, because the construction of a 3D printer depends on several disciplines.

One of the main problems we faced during this project is:

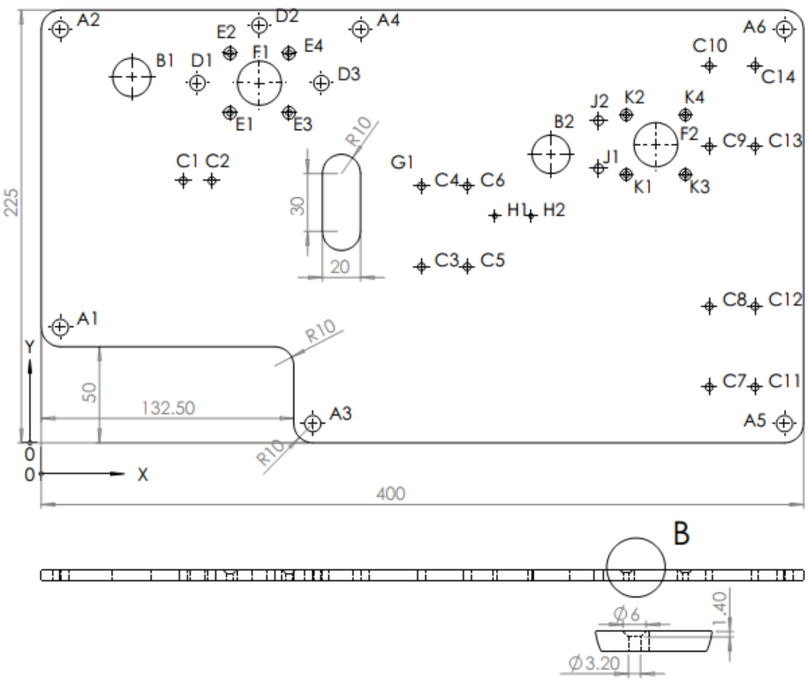
- ❖ Some parts are completely missing, which calls for alternative solutions.
- ❖ Differences exist between theoretical and practical levels.
- ❖ Creating a printer from the beginning takes a lot of time and effort.

ANNEX

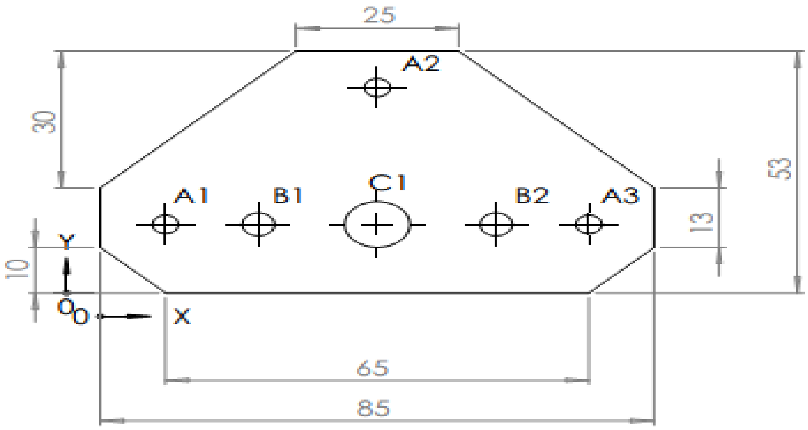
Industrial design.



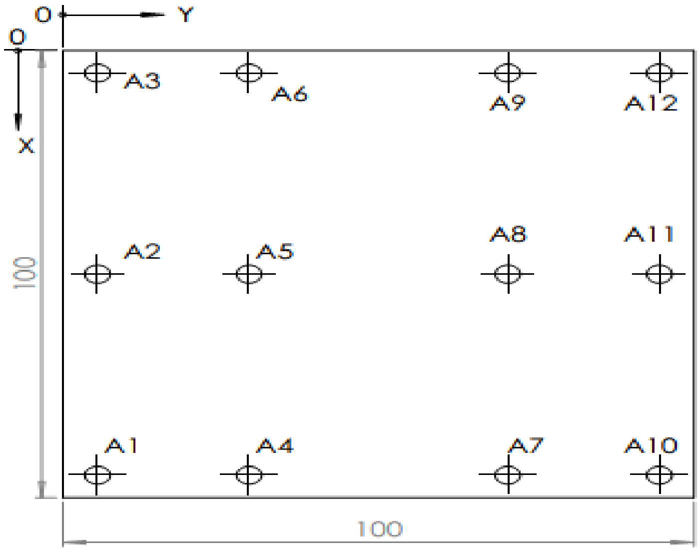
TAG	X LOC	Y LOC	SIZE
A1	10	10	Ø8 THRU
A2	10	165	
A3	10	195	
A4	30	10	
A5	142.50	215	
A6	167.50	10	
A7	370	10	
A8	390	10	
A9	390	195	
A10	390	215	
B1	35	187	Ø4 THRU
B2	35	207	
B3	82	38	
B4	114.50	8	
B5	115	187	
B6	115	207	
B7	147	38	
B8	195	125	
B9	195	175	
B10	345	125	
B11	345	175	
C1	51.47	132.46	Ø2.46 THRU
C2	52.74	84.20	
C3	127.67	84.20	
C4	134.02	132.46	
C5	202.50	12	
C6	202.50	64	
C7	245.83	12	
C8	245.83	64	
C9	265.83	12	
C10	265.83	64	
C11	309.17	12	
C12	309.17	64	



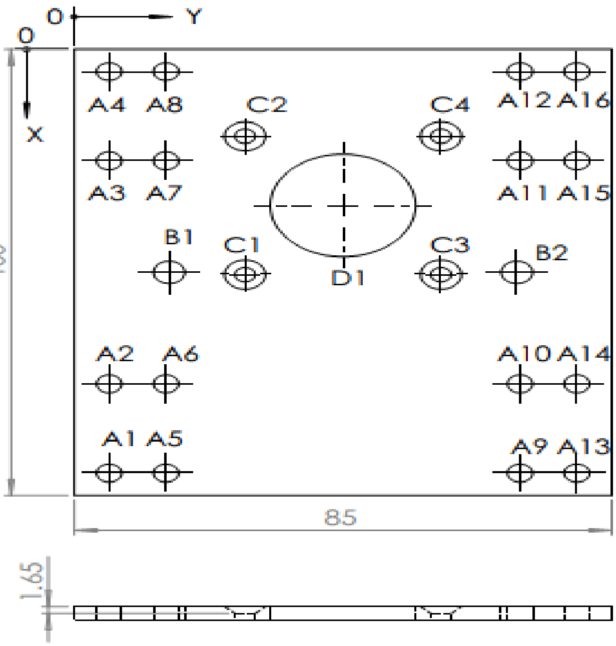
TAG	X LOC	Y LOC	SIZE
A1	10	60	Ø 8.50 THRU ALL
A2	10	215	
A3	142.50	10	
A4	167.50	215	
A5	390	10	
A6	390	215	
B1	47.50	190	Ø 20 THRU ALL
B2	267.50	150	
C1	74.50	136.25	Ø 4 THRU ALL
C2	89.50	136.25	
C3	199.50	91.50	
C4	199.50	133.50	
C5	223.50	91.50	
C6	223.50	133.50	
C7	350.50	29	
C8	350.50	71	
C9	350.50	154	
C10	350.50	196	
C11	374.50	29	
C12	374.50	71	
C13	374.50	154	
C14	374.50	196	
D1	82	187	Ø 8 THRU ALL
D2	114.50	217	
D3	147	187	
E1	99	171.50	Ø 3.20 THRU ALL ⌵ Ø 6.50 X 90°
E2	99	202.50	
E3	130	171.50	
E4	130	202.50	
F1	114.50	187	Ø 23 THRU ALL
F2	322.50	155	
G1	157.50	125	
H1	238	118	Ø 2.46 THRU ALL
H2	257	118	
J1	292.50	142.50	Ø 5 THRU ALL
J2	292.50	167.50	
K1	307	139.50	Ø 3.20 THRU ALL ⌵ Ø 6 X 90°
K2	307	170.50	
K3	338	139.50	
K4	338	170.50	



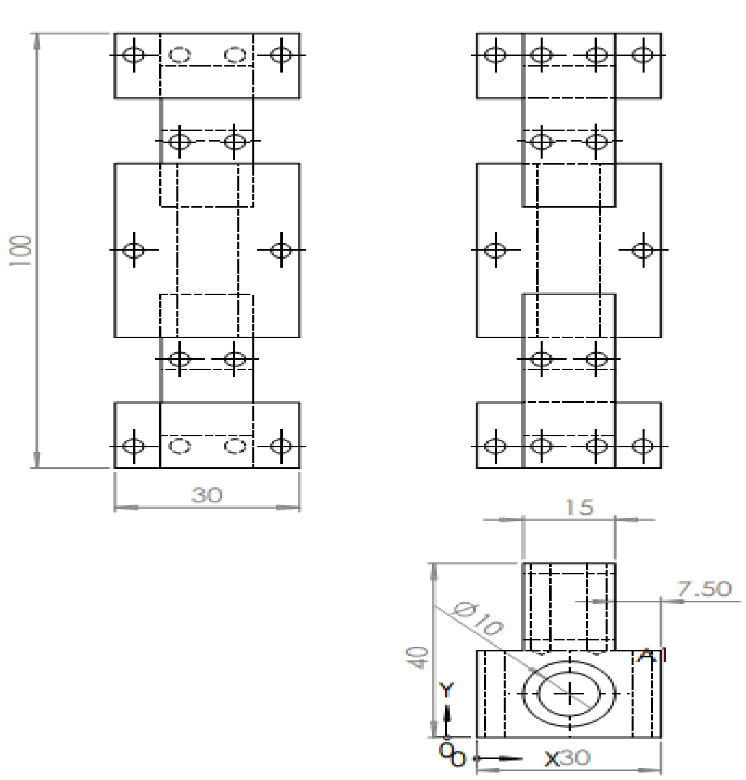
TAG	X LOC	Y LOC	SIZE
A1	10	15	Ø 4 THRU
A2	42.50	45	Ø 4 THRU
A3	75	15	Ø 4 THRU
B1	24.25	15	Ø 5 THRU
B2	60.75	15	Ø 5 THRU
C1	42.50	15	Ø 10 THRU



TAG	X LOC	Y LOC	SIZE
A1	95	5.50	∅4 THRU
A2	50	5.50	∅4 THRU
A3	5	5.50	∅4 THRU
A4	95	29.50	∅4 THRU
A5	50	29.50	∅4 THRU
A6	5	29.50	∅4 THRU
A7	95	70.50	∅4 THRU
A8	50	70.50	∅4 THRU
A9	5	70.50	∅4 THRU
A10	95	94.50	∅4 THRU
A11	50	94.50	∅4 THRU
A12	5	94.50	∅4 THRU

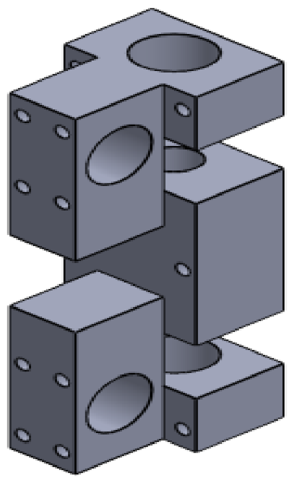


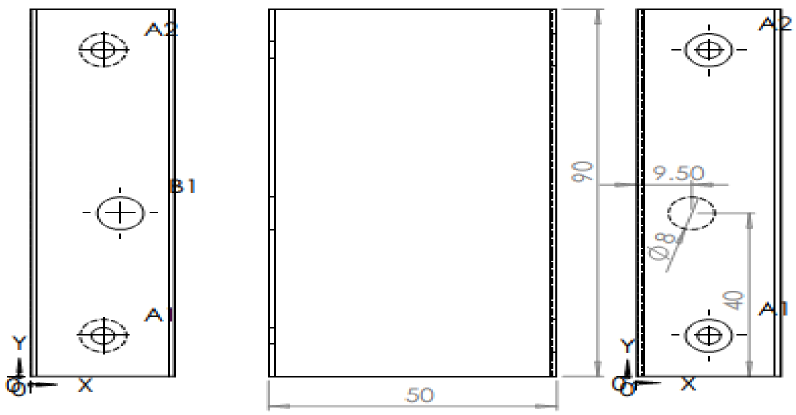
TAG	X LOC	Y LOC	SIZE
A1	95	5.50	∅ 4 THRU ALL
A2	75	5.50	∅ 4 THRU ALL
A3	25	5.50	∅ 4 THRU ALL
A4	5	5.50	∅ 4 THRU ALL
A5	95	14.50	∅ 4 THRU ALL
A6	75	14.50	∅ 4 THRU ALL
A7	25	14.50	∅ 4 THRU ALL
A8	5	14.50	∅ 4 THRU ALL
A9	95	70.50	∅ 4 THRU ALL
A10	75	70.50	∅ 4 THRU ALL
A11	25	70.50	∅ 4 THRU ALL
A12	5	70.50	∅ 4 THRU ALL
A13	95	79.50	∅ 4 THRU ALL
A14	75	79.50	∅ 4 THRU ALL
A15	25	79.50	∅ 4 THRU ALL
A16	5	79.50	∅ 4 THRU ALL
B1	50	15	∅ 5 THRU ALL
B2	50	70	∅ 5 THRU ALL
C1	50.50	27	∅ 3.20 THRU ALL ⌵ ∅ 6.50 X 90°
C2	19.50	27	∅ 3.20 THRU ALL ⌵ ∅ 6.50 X 90°
C3	50.50	58	∅ 3.20 THRU ALL ⌵ ∅ 6.50 X 90°
C4	19.50	58	∅ 3.20 THRU ALL ⌵ ∅ 6.50 X 90°
D1	35	42.50	∅ 23 THRU ALL



TAG	X LOC	Y LOC	SIZE
A1	10	15	Ø 15 THRU ALL
A2	10	85	Ø 15 THRU ALL

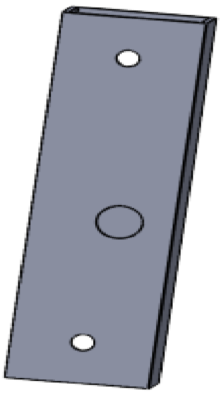
TAG	X LOC	Y LOC	SIZE
A1	15	10	Ø 15 THRU ALL

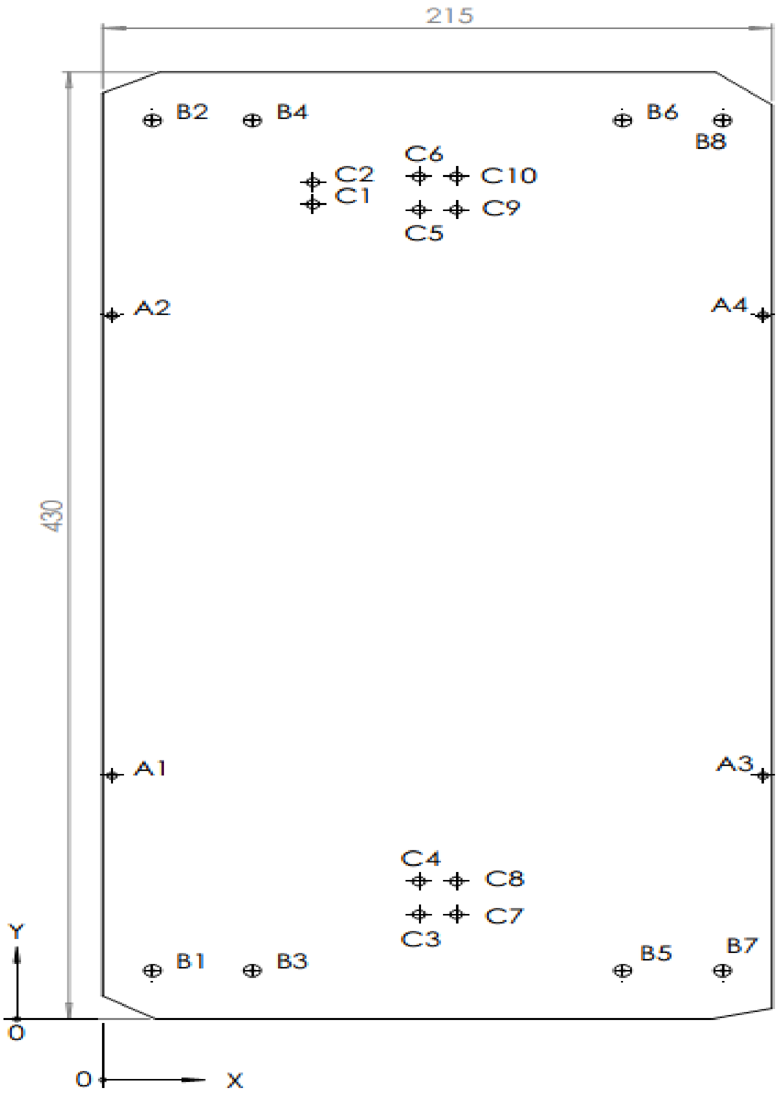




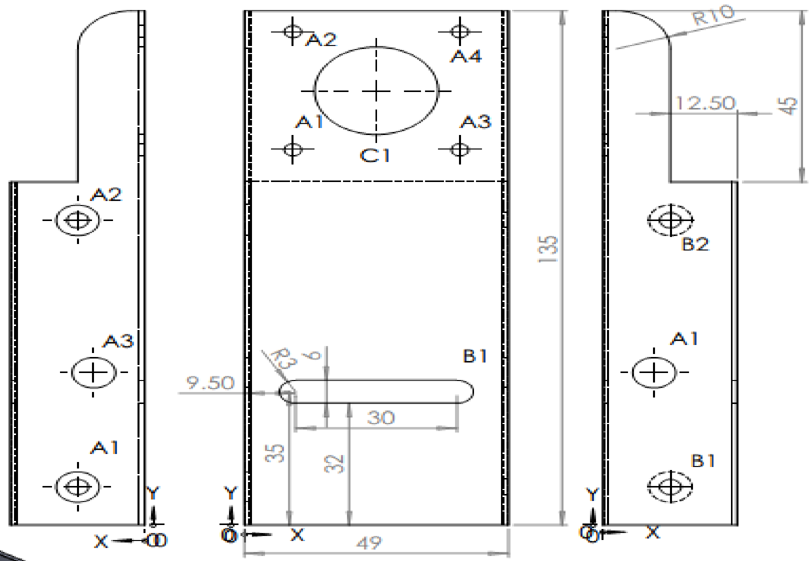
TAG	X LOC	Y LOC	SIZE
A1	12.50	10	Ø 4 THRU ALL
A2	12.50	80	Ø 4 THRU ALL
B1	15.50	40	Ø 8 THRU ALL

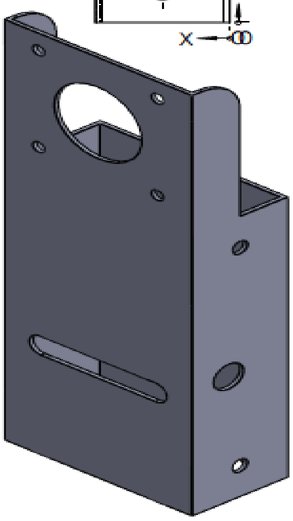
TAG	X LOC	Y LOC	SIZE
A1	12.50	10	Ø 8 THRU ALL
A2	12.50	80	Ø 8 THRU ALL





TAG	X LOC	Y LOC	SIZE
A1	2.98	110.48	∅ 3.20
A2	2.98	319.52	
A3	212.02	110.48	
A4	212.02	319.52	
B1	16	22	∅ 5.50
B2	16	408	
B3	48	22	
B4	48	408	
B5	167	22	
B6	167	408	
B7	199	22	
B8	199	408	
C1	67.50	370	∅ 4 THRU
C2	67.50	380	
C3	101.50	47.50	
C4	101.50	62.50	
C5	101.50	367.50	
C6	101.50	382.50	
C7	113.50	47.50	
C8	113.50	62.50	
C9	113.50	367.50	
C10	113.50	382.50	





TAG	X LOC	Y LOC	SIZE
A1	9	98.50	Ø 3.20 THRU ALL
A2	9	129.50	Ø 3.20 THRU ALL
A3	40	98.50	Ø 3.20 THRU ALL
A4	40	129.50	Ø 3.20 THRU ALL
B1	24.50	35	
C1	24.50	114	Ø 23 THRU ALL

TAG	X LOC	Y LOC	SIZE
A1	9.50	40	Ø 8 THRU ALL
B1	12.50	10	Ø 4 THRU ALL
B2	12.50	80	Ø 4 THRU ALL

TAG	X LOC	Y LOC	SIZE
A1	12.50	10	Ø 8 THRU ALL
A2	12.50	80	Ø 8 THRU ALL
A3	9.50	40	Ø 8 THRU ALL

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