Principles of diploma at the Faculty of Mechanical Engineering, TUL

POLITECHNIKA ŁÓDZKA
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ENGINEERING WORK
in the field of
Mechanical Engineering
Erasmus scholarship

TOPIC

Design of a machine for manufacture of elements
using Additive Manufacturing technology

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ŁÓDŹ, 2020

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General Index

List of abbreviations

3D	Three dimensions.
ABS	Acrylonitrile butadiene styrene
ASA	Acrylic Styrene Acrylonitrile
BJ	Binder Jetting
CNC	Computer Numerical Control
DLP	Digital Light Processing
DMLS	Direct Metal Laser Sintering
EEPROM	electrically erasable programmable read-only memory
FDM	Fused Deposition Modelling
LDM	Liquid Deposition Modeling
LED	Light Emitting Diode
MJ	Material Jetting
NEMA	National Electrical Manufacturers Association
PC	Polycarbonate
PET	Polyethylene terephthalate
PLA	Polylactic
RAMPS	RepRap Arduino Mega Pololu Shield
RepRap	Replicating Rapid Prototyper
SLA	Stereolithography
SLS	Selective Laser Sintering
TPU	Thermoplastic polyurethane
UFP	Ultrafine particle
USB	Universal serial bus

1. Introduction

This project is proposed as an introduction to the world of rapid prototyping and 3D printing. The main objective is the design of a 3D printer of the FDM type (fused deposition modeling), all explaining the small details and decisions made in the process. Then a list of steps and instructions will be exposed to present a manual for the correct assembly of the machine. The proposed models of the main producers and designer brands of 3D printers in the market, like Prusa, Zortrax or RepRap, will be analyzed and taken into account for creating the best design possible.

It seeks to overcome the possible obstacles that may arise in the design and try to improve some parameters of the proposed designs. Obtaining in the last place a prototype that will supply the necessities of rapid prototyping for a professional business, all with low-costs and ease to assemble. The project will be presented in a 3D model made on AutoCad, nevertheless the possibility of creating that prototype is completely possible and functional.

2. State of the Art

3D printers have the objective of creating solid three-dimensional objects from any virtual shapes created with design softwares.

The fields of application for 3D printing are extensive and varied. From engineering to medicine through architecture, education or simply leisure.[1]
Different types of 3D printing will be exposed in a table.

Type	Technology	Materials
Material Extrusion	Fused Deposition Modeling (FDM)	Thermoplastic filament (PLA, ABS, PET, PETG, TPU)
	Liquid Deposition Modeling (LDM)	Metal alloys
Powder Bed Fusion	Selective Laser Sintering (SLS)	Thermoplastic powder (Nylon)
Vat Polymerization	Stereolithography (SLA)	Liquid photopolymer resin
	Masked Stereolithography (MSLA)	

	Direct Light Processing (DLP)	
Jetting	Material Jetting (MJ)	Photopolymer resins
	Binder Jetting (BJ)	Sand or metal powder
Powder bed fusion	Direct Metal Laser Sintering (DMLS)	Metal Powder: Aluminum, Stainless Steel, Titanium
	Selective Laser Melting (SLM)	
	Electron Beam Melting (EBM)	

Table1. Printer types. [2][3]

We will explain the most used technologies next:

2.1 Stereolithography (SLA)

It was the first method developed for 3D printing. starting in 1986 by Huck Hull, It consists of applying an ultraviolet laser to a reacting resin contained in a cube. The laser solidifies layer by layer the resin until the object takes the desired form.

The quality and final surface are better compared with FDM, but on the other hand the price of this technology is substantially higher. [4]

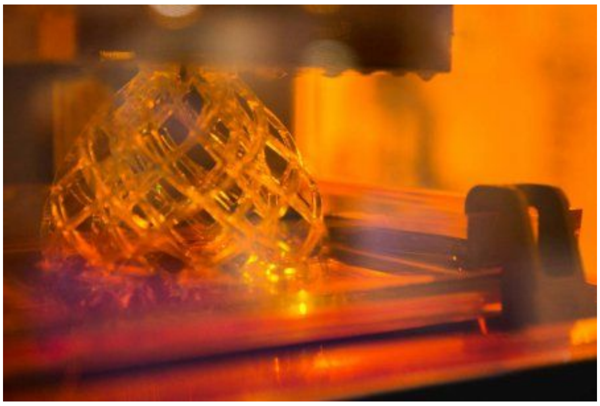

Figure 1. Stereolithography detail.[5]

2.2 Selective Laser Sintering (SLS)

Selective laser sintering is a method that consists in compacting material in dust form with which the object will be built. After, through the application of a laser, this material will be pulverized and heated up to a temperature close to the casting point.

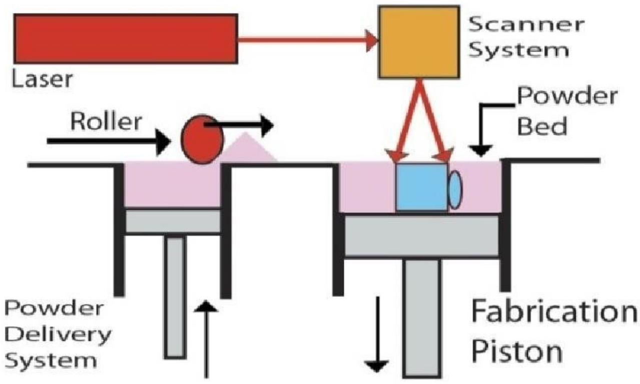

Figure 2. Selective laser sintering [7]

Obtaining good quality products, this printer is used mainly in the creation of products for the industry, such as educational centers, research centers, laboratories, etc. They are often used for the production of functional prototypes and short series, mainly by companies.[6]

2.3 Binder Jetting (BJ)

This technology is generally reduced to industrial machines. This is so unfortunate due to the large quantity of materials and possibilities they offer.

These printers have a similar way of printing compared with the common 2D paper printers. Cartridges are used too, but instead of ink they project a binder into a powder bed of the material with the pieces that will be manufactured. Colored pieces can be also made if coloring ink is added at the same time that the powder is agglutinated.[8]

2.4 Fused Deposition Modeling (FDM)

FDM tools are the main and more extended genre of 3D printers in the range of amateur and three dimension modeling. Briefly, it constructs the products adding overlapping layers of plastic materials ranging from ABS or PET to carbon fiber or flexible materials. The machine heats and extrudes a filament of the construction material for deposit forming the predesigned model. This type of construction gives the machine high levels of freedom to create items.[9]

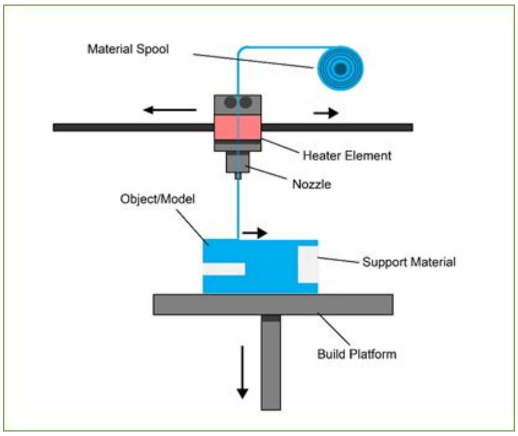

Figure 3. Fused deposition modeling[12]

Two types of FDM printers can be found, for starting the cartesian structure will be explained, which is the most extended. It is based on a moving head, guided by two fixed axes that deliver the melted plastic. It ejects the extruded liquid with the shape of every thin layer of which the piece is formed. This material is deposited on a one axis moving board that moves away from the head as it finishes each layer of the product. On the other hand, delta type machines base the movement of its head on three independent arms distributed in a triangular shape. These guides move only in the vertical axis to obtain the right position of the pointer on top of a circular fixed board. [13]

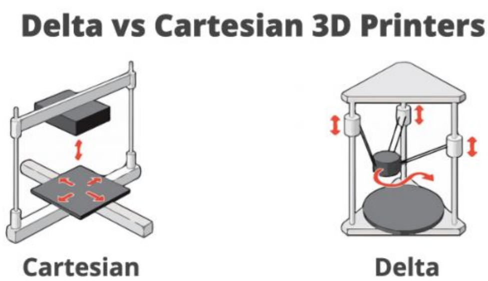

Figure 4. FDM printers types.[13]

To compare both designs delta printers have lower accuracy and with it, reduced finish quality of the surface. However, delta printers have main advantages like their increased velocity and available height to print, all because of their stretched structure. These pros are even more profitable when the objects have a circular design. As said before, cartesian printers are widely used around the world, that gives them far more support than delta machines. Due to its popularity it is easier to find parts to repair or improve this machine.

Figure 5. 3D printed gear.[14]

Printing small and simple objects is the main purpose of this printer. Products can be obtained in a cheap and fast way. However, trying to print larger or more complex designs can be harder for this machine due to its limiting dimensions or because of how time consuming it is.[10]

Regarding designs with hanging parts, the software used by the printer is able to create supports in order to hold these extensions. After the manufacturing is done, these parts have to be cast away from the piece.
Surface finish of the products is one of the main cons of FDM printers, owing to the mode of depositing the material by the extruder cone.

It is really easy to start printing products due to its simplicity. First of all a design of the product is needed, it can be obtained in almost any drawing program such as AutoDesk or Blender. Once the design is available, converting the file to .gcode is needed, it is a type of file where the object has been transformed into a set of instructions that the 3D printer is able to read and follow. The software Cura is a good option to process it.[11]

The last step in the obtaining of the product consists in the separation of the piece from the printing platform. It can be easily removed by hand or using water and detergent. It is important to be gentle with the treatment of the piece, small ones can take 1 hour to print while more complicated pieces can last one full day. After the separation of the piece, the only left to obtain the final product is to remove all the supports if there is any and give the piece a last polish and paint finish.

Use of the Fused Deposition Modeling printers is widely extended due to its easiness to use and its broad fields of utility. For example, the creation of functional prototypes in industry or design, on food packing due to its use of non-toxic materials or in hands of non-professional users to play around with it.[10]

This is the type of 3D printer that the course of this project will develop. This option and its capabilities are found very effective and essential in the Mechanical Engineering scope.[9]

Figure 6. Ready to separate design.[15]

3. 3D Printers review

3.1 Remarkable designs for 3D printers

Now some of the current designs that worldwide brands of 3D printers have proposed as solutions will be described. Three solutions for professional industrial manufactures will be exposed, and one design aimed for non-professional clients. There is a big difference between the price range of these 3D printers but the capabilities of them also differ substantially. [16]

Figure 7. Different FDM options.[16]

3.1.1 Ultimaker

Starting with the company Ultimaker, in their catalogue the 3D printer Ultimaker S5 Pro Bundlecan be found. This professional machine has the largest work volume of the machines that will be analyzed, it allows us to build products up to 330 x 240 x 300 mm. Two remarkable features that make it different from the rest of printers can be founded. Both features are located next to the printing zone, on the top part the Air Manger and on the bottom the Material Station.

The first device filters the air to reduce the UFP (Ultrafine Particles) up to 95%, granting a safer working area in the facilities. This gives security for small spaces or high producing volumes. In the base the Material Station can be found, this annexation consists of 6 compartiments to stock different coils of materials.[17]

Figure 8. Ultimaker S5 Pro Bundle[17]

The machine is designed to change the material whenever the making of the product requires it, or replace the empty coils for new full ones. This capacity gives versatility and speed to the machine but the main advantage is the possibility of printing without the need of an operator. It is also remarkable that this printer gives the user the freedom to choose plastic materials manufactured by third parties.

3.1.2 MakerBot

One of the solutions that MakerBot company proposes us is MethodX. This professional FDM cartesian 3D printer allows us to obtain a wide variety of designs while maintaining good accuracy and surface finish. With a height of 65 cm and a base of 44 x 41 cm, it grants us the possibility to print objects until 19 x 19 x 19,6 cm in single extrusion mode. Its heating chamber allows it to produce stronger parts than a heated building plate. With temperatures of the chamber that come up to 110ºC, produce stronger pieces than a heated plate printer. It can print pieces from real ABS, ASA, nylon and other plastic materials produced by MakerBot.[18]

Figure 9. MethodX by MakerBot[18]

One of the main features of MethodX is that it is allowed to print objects in two different materials with its special nozzle, this let us for exemple, to print the supports of the design in a water soluble material to obtain more freedom when printing with hard plastics. Finally it is assumed that MethodX has a high velocity of printing, twice as fast than other designs in some cases. The max material flow rate is 50 mm^3 while the print head movement speed can reach up to 500 mm per second[18]

3.1.3 Prusa

Now it is the turn of one of the most awarded manufacturers. The product that highlights in their catalogue is the Prusa i3 MK3S 3D printer. Unlike the rest, this device is not covered by a protector case so the rails and the base are exposed to the environment. This, along with lower overall features as components quality and reliability, means that the cost of them will be substantially lower.

Figure 10.Prusa i3 MK3S[19]

Their working zone span is 25 x 21 x 21 cm, with a velocity of the nozzle of 200 mm/s. Also allows a wide variety of materials and uses sensors to detect the lack of filament or the overheating. All of this with a reduced noise of operations. Prusa offers both already assembled printers as well as special kits to assemble it by the client own, their catalogue also contains upgrading kits to increase the number of simultaneous materials that can the nozzle print. In summary, Prusa designs allow to manufacture prototypes for a lower price maintaining acceptable technical characteristics.[19]

This type of printer will be the main focus for the objectives of designing the projected 3D printer. All of this due to its easy assembly, economic sustainability and open source code.

3.1.4 Zortrax

To finish this overview of 3D printers brands we will take a look at the best printer that Zortrax has in their catalogue, Zortrax M300 Dual. This polish brand offers a good amount of products and competitive technological options. With a dimensions of 265 x 265 x 300 mm of the working area, this printer gives a lot of benefits in a reduced space.[20]

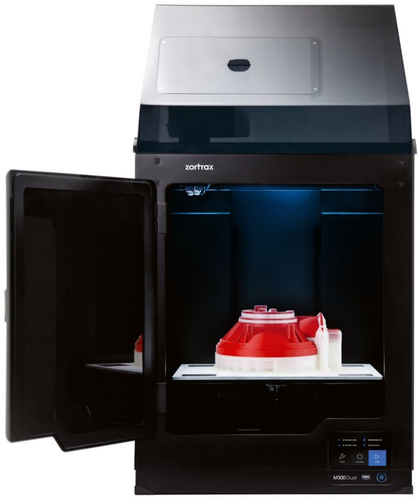

Figure 11. Zortrax M300 Dual[20]

Counts with a double nozzle to extrude simultaneously the base material and a water soluble option for the supports, as the MakerBot model. It supports external filaments in both single and double modes, and uses some sensors to pause the printing in case that these filaments run out. It is also protected in the case of power outage, resuming the printing in the same spot where it was stopped. In addition, Zortrax offers their own software Z-SUITE 2 that provides the user with more flexibility and optimization features. [20]

3.2 Printers Specifications

In the next table it is compared the technical specifications of the different main 3D printers available in the market. After analyzing the RepRap project, the conclusion is that their designs and objectives are really similar to these project ones. For that reason one more RapRep project has been added, Ormerod.

3D Printer	Working area	Accuracy	Layer thickness	Extras	Price
Ultimaker S5 Pro Bundle	330 x 240 x 300 mm	0.25 mm	0.0025 mm	Air manager and Air station	10 500 €
MethodX by MakerBot	190 x 190 x 196 mm	0.1 mm	0.2 mm	Double nozzle - Carbon Fiber Version	4 999 €
Prusa i3 MK3S	250 x 210 x 210 mm	0.4 mm	0.05 mm	Auto assembly kit	769 €
Zortrax M300 Dual	265 x 265 x 300 mm	0.4 mm	0.15 mm	Double nozzle	4 200 €
Ormerod	200 x 200 x 200 mm	0.2 mm	0.1 mm	RapRep Open software	Discontinued

Table 2. 3D printers comparison.
[17][18][19][20]

3.3 Design requirements

Based on the market state of the 3D printers and the advantages and disadvantages of the different design options, some design requirements that the final design should take in account have been established.

The requirements to be taken into account are mainly of two types: those of a structural type and those of an electronic or control type. Both based on the possibilities of assembly and aiming for an easy assembly and acceptable costs.

- Regarding the structural and mechanical requirements, the following should be highlighted:

3.3.1 Print dimensions

The print volume must be able to exceed the 200x200x200mm typical of a RepRap printer.[19] Lower dimensions can not be aimed for industrial and rapid prototyping processes.

3.3.2 Structural design

The structure of the printer must be modular, allowing the total redesign or parts of it. In relation with the type of structure, 2 options can be discussed. Cube closed structure or gantry structure like Prusa i3.[19]

Figure 12. Closed Cube structure[21]

Figure 13. Gantry structure[22]

3.3.3 Resolution

The final resolution of the printer must be at least 200 μm or 0.2 mm. With this, a suitable accuracy in relation with other 3D printers is ensured.[19] For the attainment of this accuracy value focus of all efforts should be aimed in selecting an acceptable nozzle, correct stepper motors and precision pulleys and spindles.

- Regarding the electronic type requirements, the following should be highlighted:

3.3.4 Handling and control

The 3D printer must be able to be controlled both autonomously and with a computer. It has to be able to be controlled with a computer with the main operative systems or on the other hand be controlled in a LED screen attached in the printer. The models will be passed to the printer via USB in the second option.

3.3.5 Control electronics

The control electronics must be free and low-cost hardware. All of them easy to access via online shopping and with good reliability on the online support and users manuals. A lot of options are available in this part but some of them are too advanced for this project, for this reason the most simple but adequate devices will be selected.

3.3.6 Control programs

The software and firmware used must be of free and multi platform license (PC, Mac and Linux). The most common ones will be analyzed, selecting the best options taking into account the easiness to use, the freedom to customize the printing and the software with a background community with regular updates.

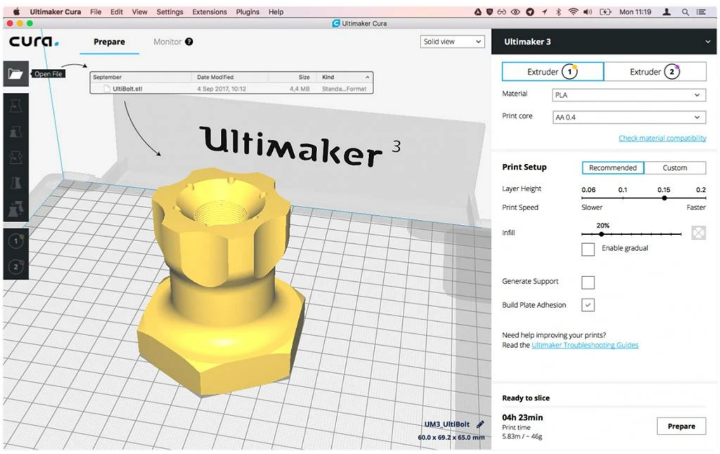

Figure 14. 3D printing software[23]

4. Solution Analysis

This chapter will report all the different alternatives studied, comparing the advantages and disadvantages of each one, and finally choose a solution.

For better structures it will be divided into three parts, one with the structure, a second one with the mechanics and the last one for the electronics.

4.1 Structure

This section is in turn divided into support and base structure, in which the different alternatives studied are valued.

4.1.1 Support structure

As explained before, structure can be divided between closed structure or gantry structure. The closed structure has been selected due to their better structure stability, the possibility of isolating the working zone and the ease for making that zone bigger. Selecting this structure, ensures us the fact that the movement of the Z axes will be carried out by the base of the printer.

The working area will be higher than 200 x 200 x 200mm and in order to make the structure as versatile as possible, 4-guide aluminum profiles are used. Specifically, T-Slot 20x20mm Aluminium 6063-T5 profiles, as shown in the following images.[25]

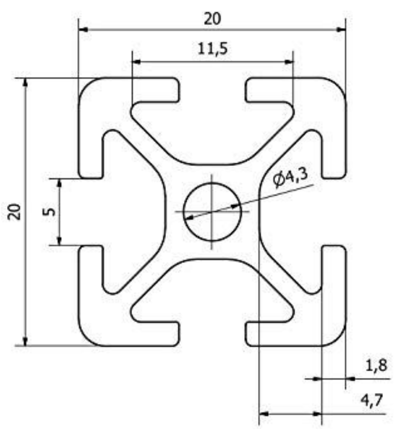

Figure 15. Profile plan[24]

Figure 16. Profile view[24]

To guide the mobile base of the printer, 60x20 mm profiles will be used with the wheel kits on the z axis.[26]

To join all parts of the printer (motors, extruder, guides etc.) to the aluminum structure, a 3D printer has to be available with which all these parts will be printed, previously drawn AutoCad Inventor. With this, all the errors will be minimized due to a previous visualization of the final position of the pieces.

4.1.2 Base

The difference between using a heated base and not using it is huge. Using a heater device on the base allows us to manufacture products with a larger quantity of materials and thickness of printing filaments. It will increase the price substantially but is totally worth it.[27]

Also, instead of using the typical crystal support, this printer will use an aluminum base as a printing zone. This decision is based on the price and dimensions of both options.[28]

The only option available for our dimensions of 220x220 is the Richer-R Hot bed for 3D printers. This device ensures fast and long lasting heat as well as a competent price.

Figure 17. Richer-R Hot bed [29]

4.2 Mechanics

In this part the mechanics part will be presented. Parts as the motors, the guides, the extruder or the threads and spindles. The elections made in this part will be based on the ease to access and implement the product, the costs and the quality and capabilities.

4.2.1 Motors

Starting with the motors, stepper motors are the best option. Combining them with control drivers a good accuracy and precision can be ensured.

The parameters of the motors that had been looked for are 200 steps motors and a maximum current of 2A so with this the chosen motor is Motor NEMA 17 with 200 hundred steps and 1,7A and 2,8V.[30]

Figure 18. Motor NEMA 17[31]

4.2.2 Guides

The market of linear guides is really wide nowadays, linear guides can be found from the typical systems of smooth rod and linear bearing to the more complex and expensive guide systems for numerical control machines.

Taking in account the main objectives of the design of this printer, the reduction of the costs as well as the complexity, the guides by rod and bearing will be the main design for this purpose. Through pulleys and spindles the traction will be delivered, with this, the quality of the product is ensured as well as the competent costs. Obtaining a similar design to typical RapRep printers. [32]

Figure 19. Rod and bearing Guide[33]

The list with the exact components needed to build the guide as the whole printer will be exposed in further points of this thesis.

4.2.3 Extruder

The extruder is in charge of the most important function in the printer. It melts the material and deposits it on the plate with the correct thickness.

There are different designs for this function, ones with the motor connected to the hotend or bowden type, when they are separated. Also, the gear can be connected directly or they can be connected through a reductor gear.[34]

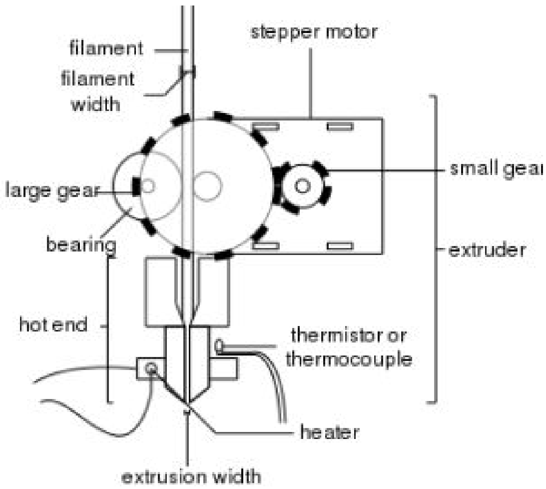

Figure 20. Extruder parts[35]

In relation with the hotend, it is the last part of the extruder, the heater and nozzle can be found. It is divided into heatsink, the cooled part and the heating block. This last part also contains a temperature sensor and the heating element.[35]

There are a huge number of options at the time of buying an extruder, the costs can change from 20€ to 200€ for the most complex and already assembled ones. In this project the scope will be focused on finding an extruder in the middle of the spectrum, the main option for this characteristics is the extruder bowden type E3D. This extruder allows a good quantity of materials as well as having a competent price.[34]

Figure 21. Extruder E3D[34]

4.2.4 Pulleys and spindles

These last mechanical components are in charge of transferring the movement from the motors to the nozzle. The minimum movement transferred will be based on the minimum step of the motor.

The number of teeth in contact of the pulleys and the spindles should be enough to ensure a good resolution as well as reducing the possible slippage. For that reason 6 teeth have been chosen as the least number of teeth in contact.[36]

The main pulleys and spindles designed specially for 3D printing that can be found in the market are Gt2 and Gt3. Finally Gt2 pulleys will be chosen due to their 20 teeth given us a step of 2 mm each. The spindle chosen needs to have 2 mm of step each spin too, trapezoidal spindles will be chosen due to their reliability. Specifically Tr8x2.0.[36]

Figure 22. Spindle[37]

Figure 23. Pulley[38]

4.3 Electronics

In this space the decisions will be made around which control board will be chosen. 3 different options will be studied and one of them selected. Selecting good products in this part of the project is highly important because the 3D printer will be controlled by this hardware, not reliable hardware can conduct to low quality paintings and low life expectancy for the printer.

The options analized in this project vary between devices with few technical options and controllers to devices capable of controlling more thermocouples and controllers for fans and extruders.[39]

- **SAV-MKI**: This the best spain designed board, part of the RapRep project, this board has been designed aiming to improve some of the previous designs but trying to maintain the low costs and good functionality.[42]

- **RAMPS 1.4**: Ramps or RepRap Arduino Mega Pololu Shield is a board designed to support all the electronics and mechanics needed to run a RepRap printer for low cost and all in a small package. It is based on Arduino MEGA.[40]

- **RUMBA**: RepRap Universal Mega Board with Allegro driver. This board is the ultimate and most complete feature used not only for RepRap also for other CNC devices.[41]

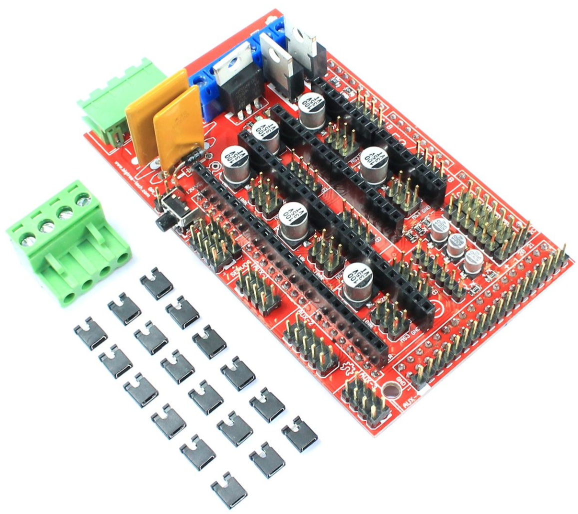

Figure 24. RAMPS Board with jumpers.[43]

Features	SAV-MKI	RAMPS	RUMBA
Extruders	1	2	3
Fans	3	3	2
Limit switch	4	6	6
Temperature Sensors	2	3	4
CPU	8 bits AT90USB1286	Arduino Mega 8 bits ATmega2560	Atmega2560
Speed (MHz)	16	16	16

Table3. Control boards comparison.[39]

Checking the different options available and its features as well as the costs and sales for them, it is clear that RAMPS is the solution that highlights the others and the most famous option. Also, sales packs are available offering a Mega 2560 3D Printer Driver Kit with RAMPS 1.4, A4988 Stepper Motor Driver and the LCD 12864 Graphics Controller. All for a competent price. With this all the controllers are supplied. [43]

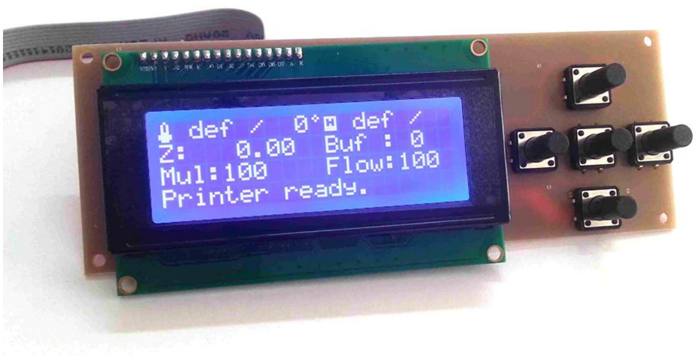

Figure 25. 3D printer LCD screen.[44]

In relation with the firmware, Marlin has been chosen due to its better control of temperatures as well as its wide possibilities of configurations.[46] Some of the characteristics of this firmware are exposed next.

- Always look for maintaining a high speed.
- Automatic bed leveling and compensation.
- Dynamic Temperature setpoint.
- EEPROM storage of several settings.
- Filament Runout Sensor support.
- Filament Width Sensor support.
- High step rate.
- Improve base movement for real linear acceleration.
- Interrupt based temperature protection.
- LCD menu system for standalone SD card printing.
- LCD support.
- SD Card support.
- Up to 4 Extruders supported.

[45]

5. Final results

The final solution of the project will be presented in this part, following always the previous defined characteristics. Also the correct configuration and parameter calculations obtained in further steps. All the parameters of the printer will be exposed in a table format next.

Group	Feature	Maximum value
Temperatures	Extruder temperature	275ºC [47]
	Max Hot bed temperature	120ºC [29]
Volumns	Exterior volume	500x540x630 mm
	Interior Volume	354x388x380 mm
	Working zone volume	250x270x300 mm
Extruder	Nozzle diameter	0.4 mm [48]
	Speed	35 mm/s [48]
	Filament diameter	1.75 mm [48]
Movement	X and Y axis resolution	12.5 µm
	Z axis resolution	625 nm
	X and Y axis max. velocity	400 mm/s
	Z axis max. velocity	3 mm/s
	X and Y axis max. acceleration	1500 mm/s^2
	Z axis max acceleration	100 mm/s^2

Table4. Final result parameters.

6. Mounting manual

This manual will be structured in three parts, the first part will explain all the mechanical mounting, taking account of the structural parts as well as the rest of the structural parts. The second part will explain all the electrics and electronics of the project. All the parts will be followed with images to help with the mounting. Lastly in the third part we will explain some considerations that have to be taken in account for the correct working of the machine.

6.1 Structural and mechanical mounting

1st Step

4 20x20mm profiles to form the framework, 16 unions and 34 allen screws plus the tee nuts. As we can see in the image. The distance of the profiles are 500 mm. The LCD support will be connected with two screws.

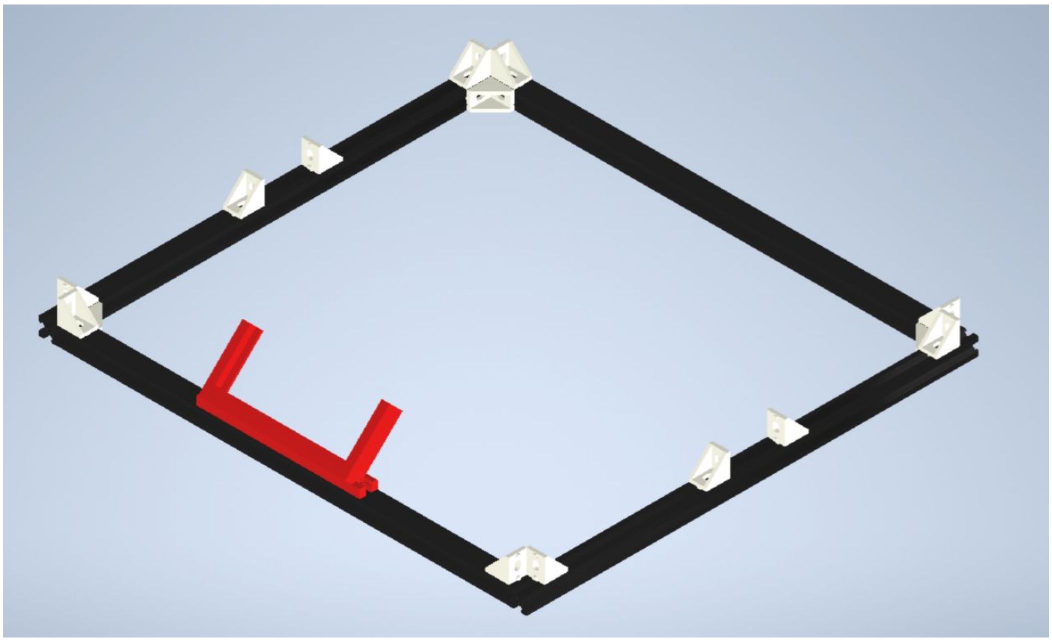

Figure 26.Base structure.

2nd Step

The under cover of 500x460 mm is deployed and 6 more profiles are established. 4 20x20x500mm and 2 60x20x500mm that will be used to guide the Z axis. Everything is fixed with tee nuts and screws.

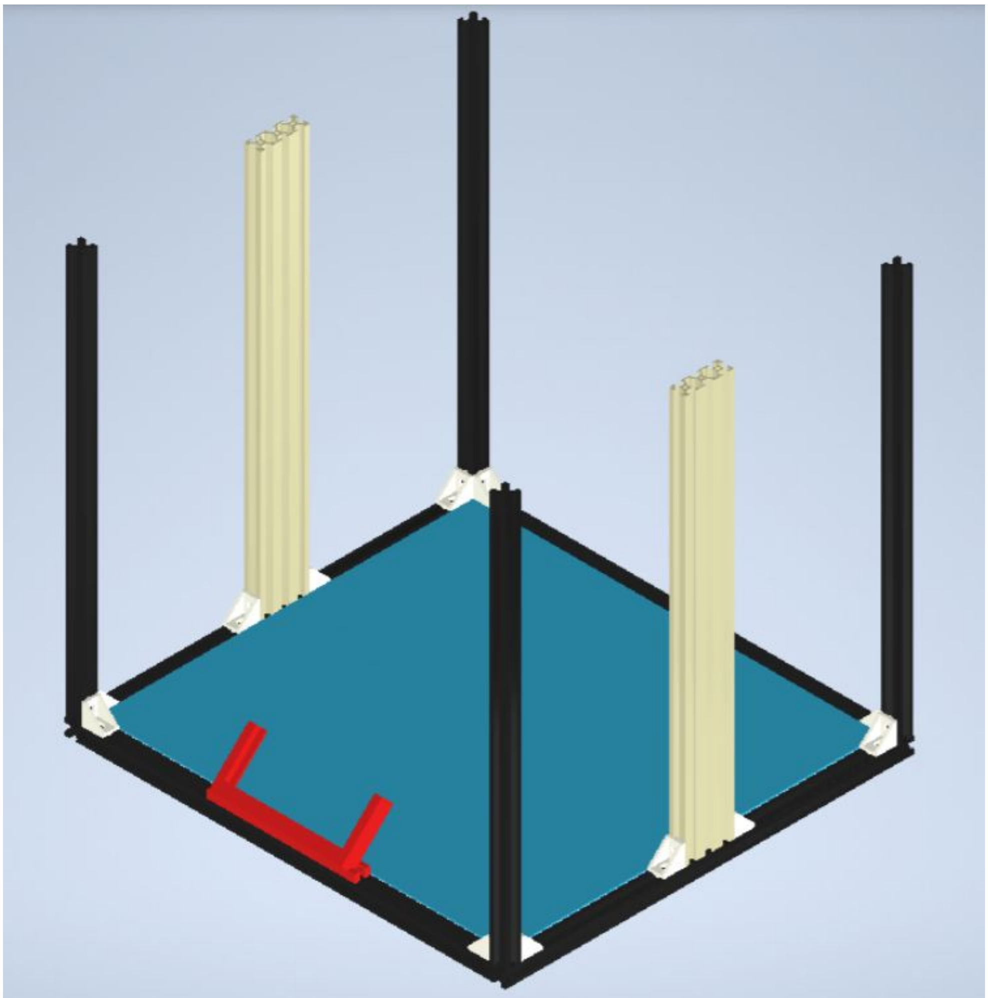

Figure 27. Z axis structure.

3rd Step
The base is fixed as shown in the image. This red part will be used as the end of the spindle so a bearing zz688 should be installed.

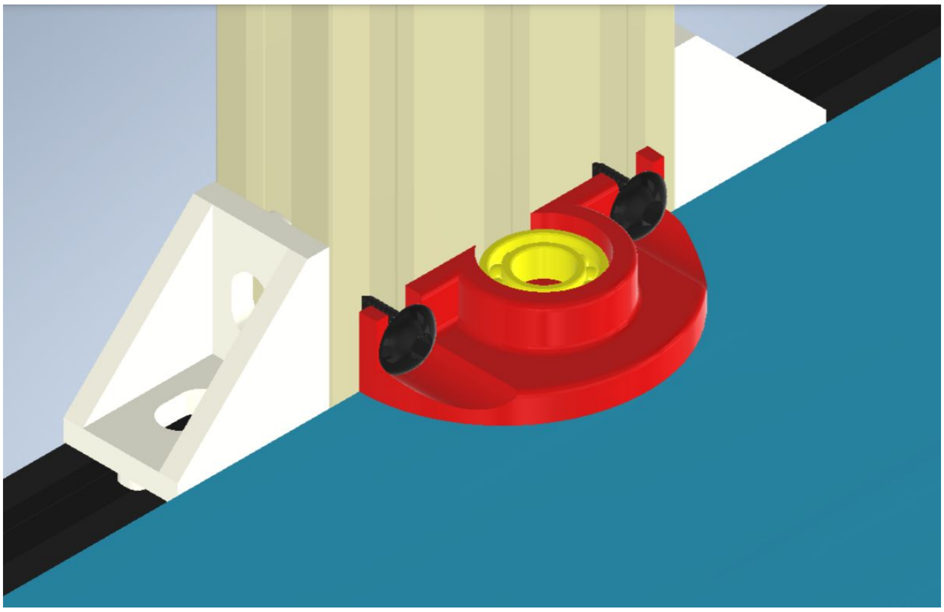

Figure 28. Base bearings detail.

4th Step
8 unions for the profiles are installed and 4 bigger unions for the X axis (green) with M10 dipsticks and LM10UU bearings.

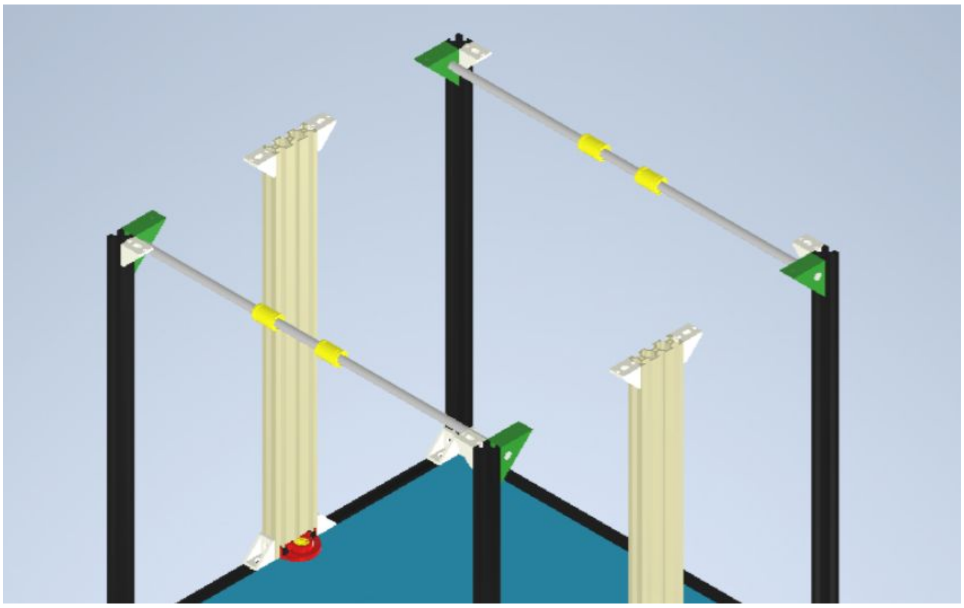

Figure 29. X axis structure.

5th Step
In this step the coil holder is installed with a M5x10 mm on the right part as well as the back cover of the printer wit M3x6 mm.

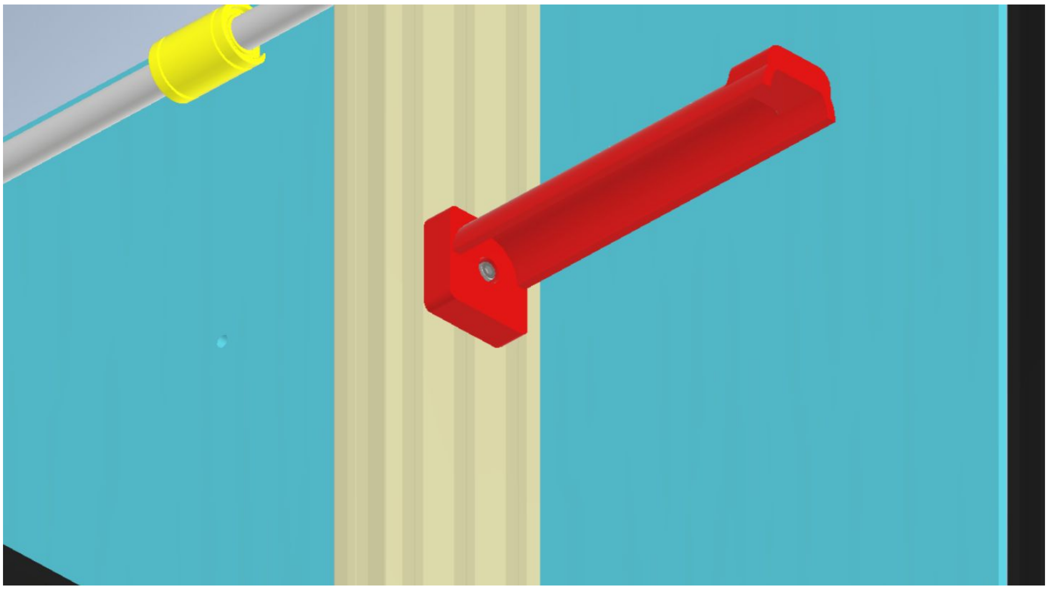

Figure 30. Coil Holder detail.

6th Step
In this step the box will be closed using the same framework as used to form the base. Profiles 20x20x500 mm. Also the supports for the X axis should be installed as shown in the figure.

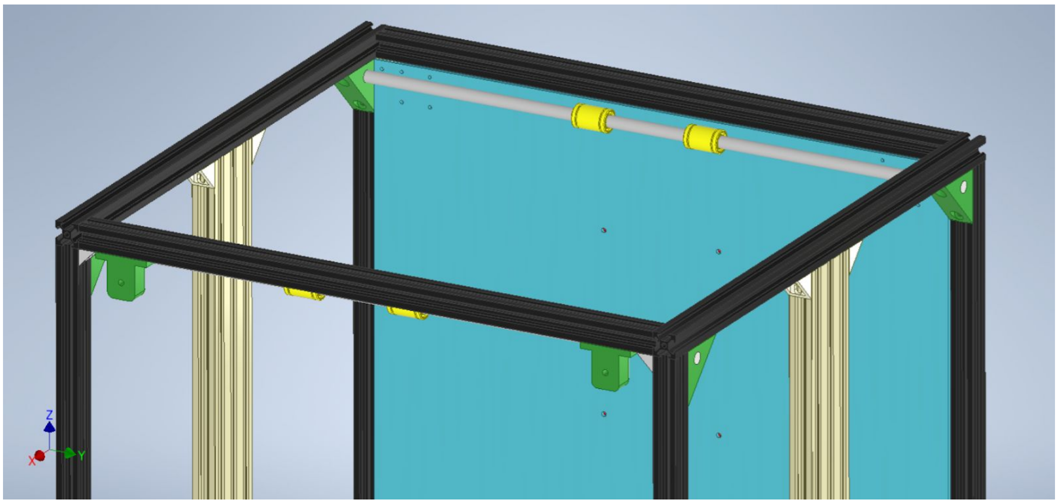

Figure 31. Box top structure and X supports.

7th Step
In this step the support for the arduino, the power supply and the support for the On/Off switch are placed as shown in the image.

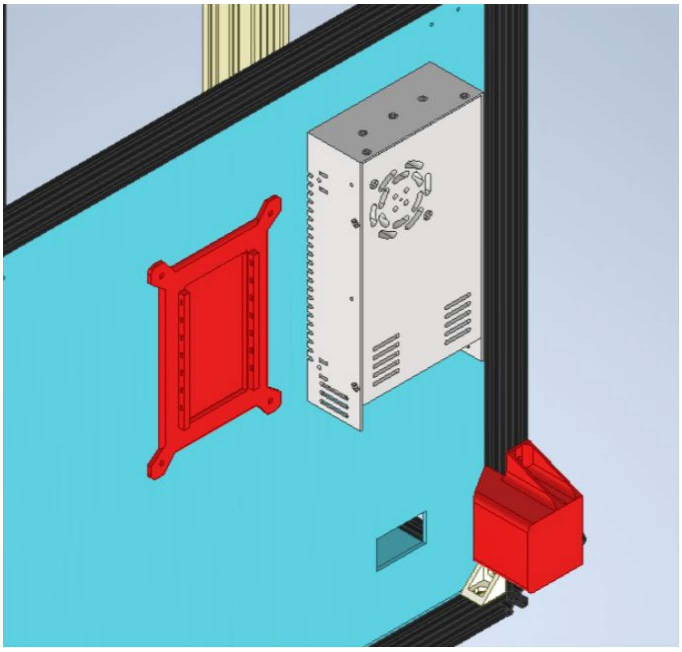

Figure 32.Box back disposition.

The power supply female as well as the switch button should be also installed in this step.

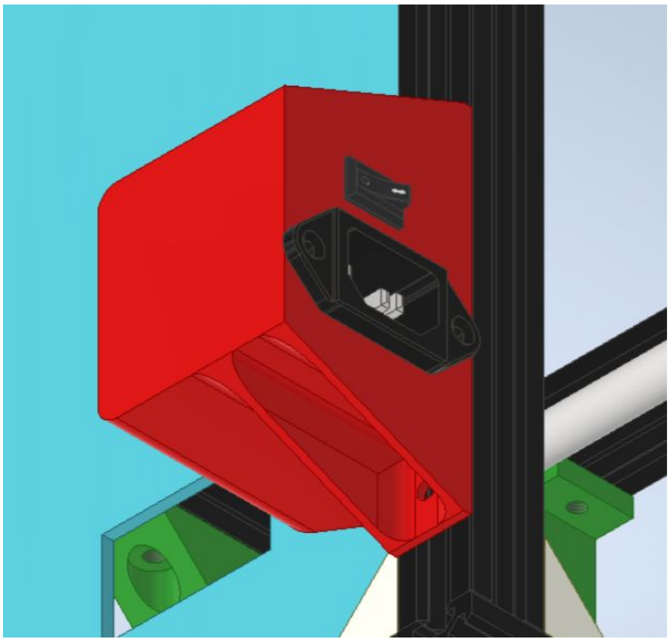

Figure 33. Switch and On/Off detail.

8th Step

The axis for the belt should be installed in this step as well as the support with a zz625 bearing. We will use 4 M3x10 mm screws.

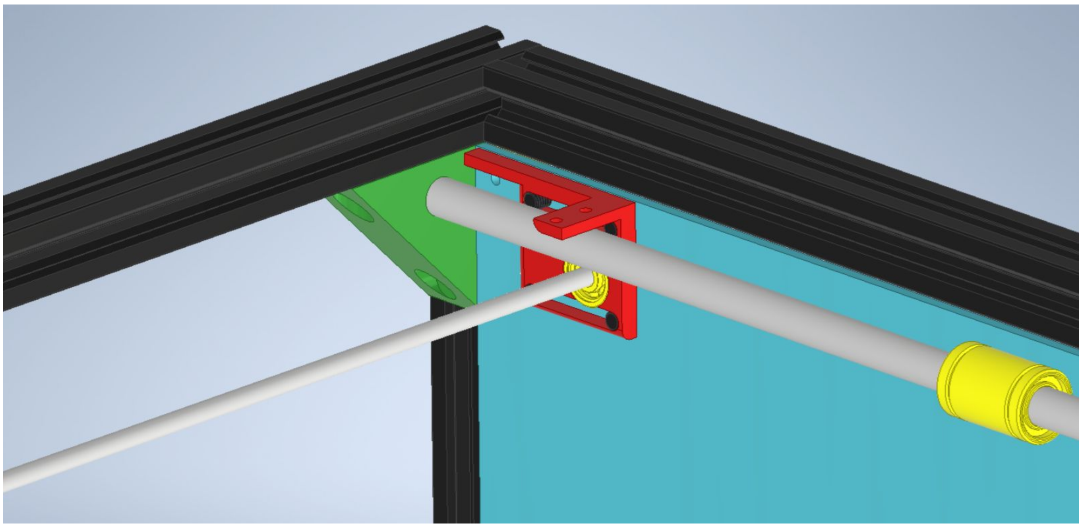

Figure 34. Axis support detail.

The same is done with the other axis but in this case the motor should be connected with the coupling printed piece and the motor separator.

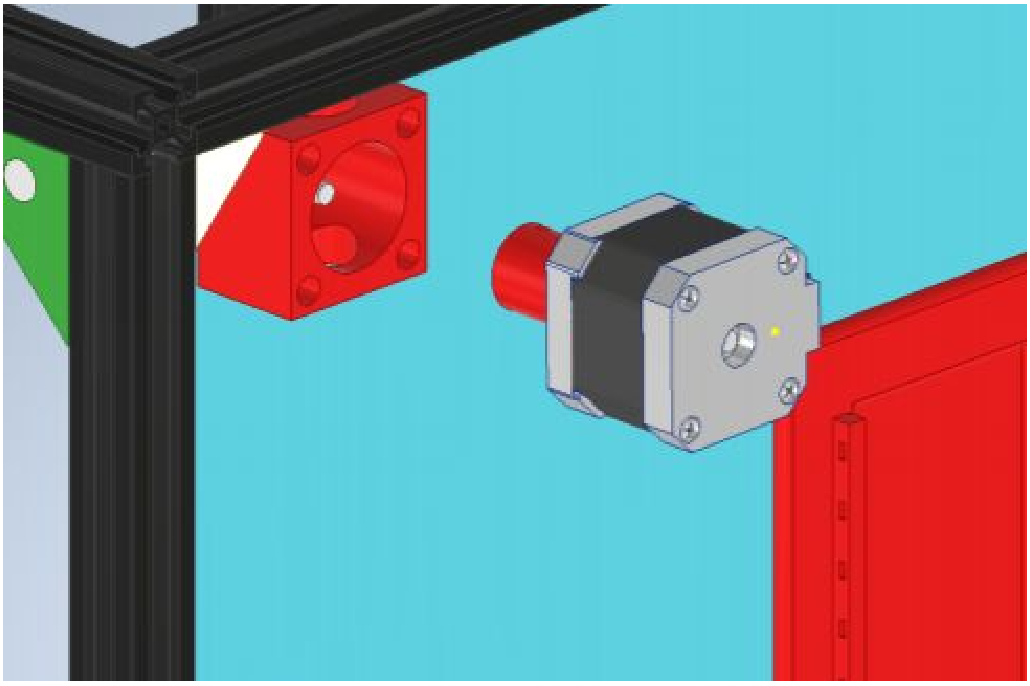

Figure 35. Exterior motor detail.

9th Step

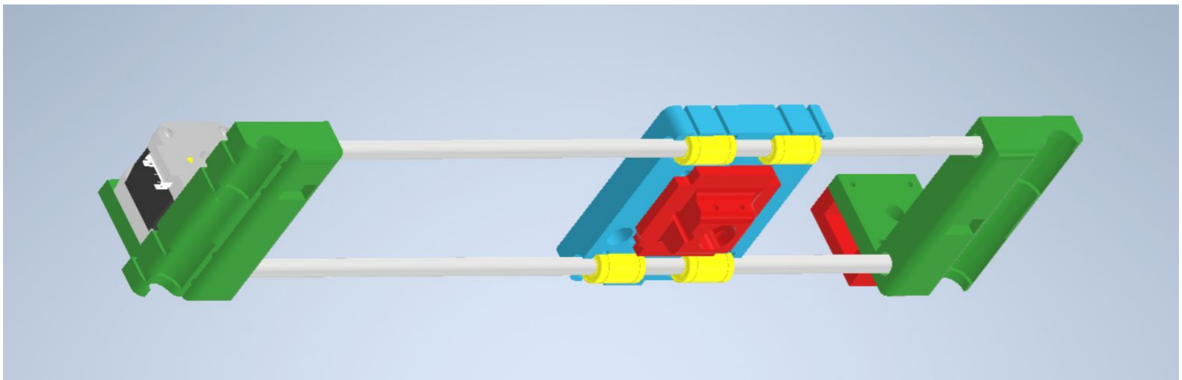

Figure 36. Moving head detail.

We connect the M8x400 mm rod to the joint bracket between X axis and Y axis, so insert the LM8UU linear bearing into it.

Next, screw the stepper motor with Gt2 pulley onto the shaft and tighten the zz608 bearing cap with M3x10 mm screws. The extruder support frame is additionally connected, everything is placed on the bearing and stuck with flanges.

10th Step

In this step the mobile base will be constructed. 4 20x20 profiles should be connected in a rectangle shape with the dimension of the pre designed base. Also 4 springs should be installed for calibration. Finally, ACME blocks should be installed as well as universal plates in the sides, all to be connected to the Z axis.

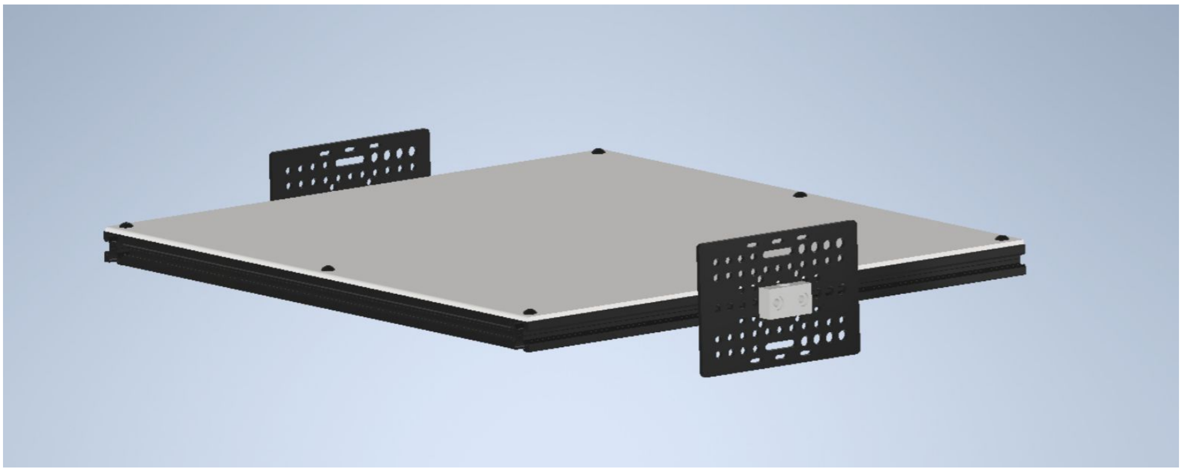

Figure 37. Moving base.

11th Step
The movement wheels will be installed next.

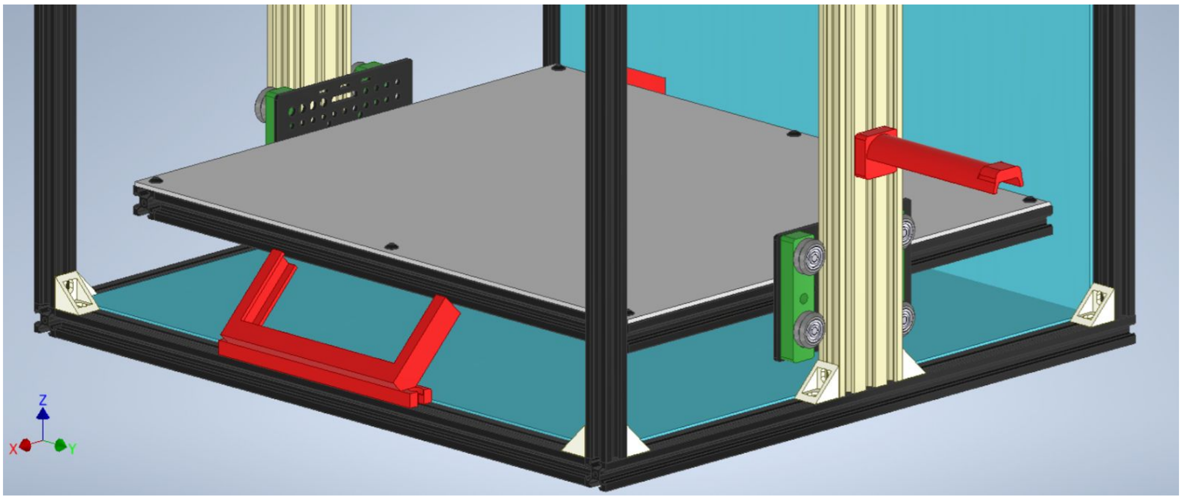

Figure 38. Z axis wheels detail.

As shown in the figure, using the pre designed part the wheels are assembled with M5x40 mm and using the profile as a guide.

12th Step
Once the bottom is placed, the "rod plate" is fixed to the structure, the trapezoidal spindle should pass through them, and it is center to them with zz688 bearings, then the flexible aluminum coupling is fixed , and the motor shaft to the spindle also, the distance between them will be marked by the gasket on each engine. Finally, the motor should be tightened with 3 M3x45 mm screws.

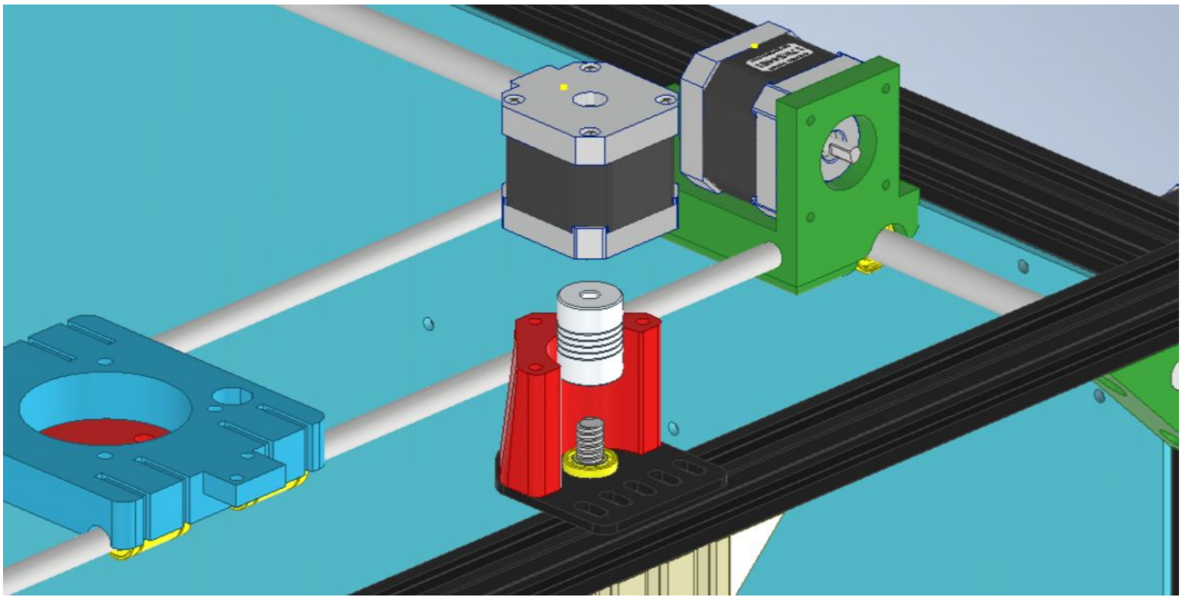

Figure 39. Z axis motor detail.

13th Step
This final step consists in fixing the guide for the plastic filament.

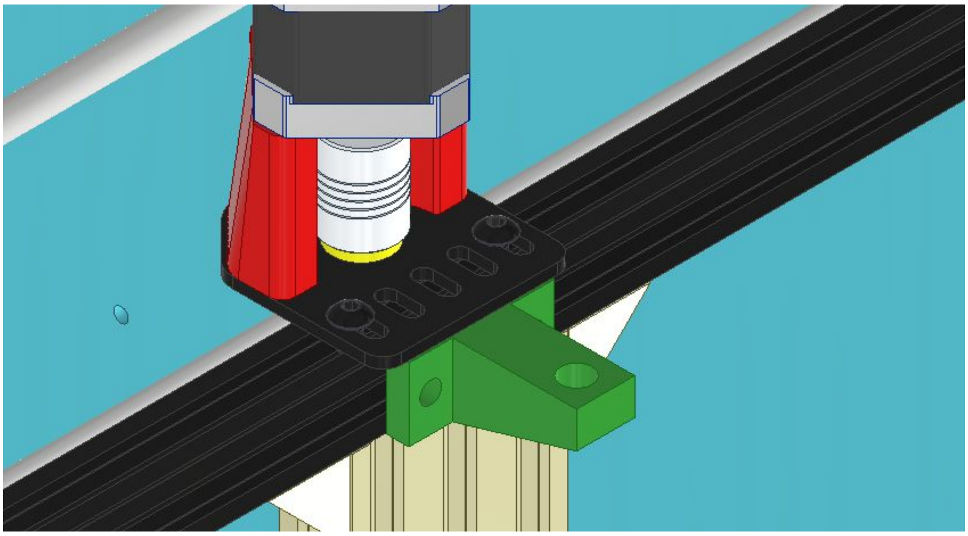

Figure 40. Filament guide.

14th Step

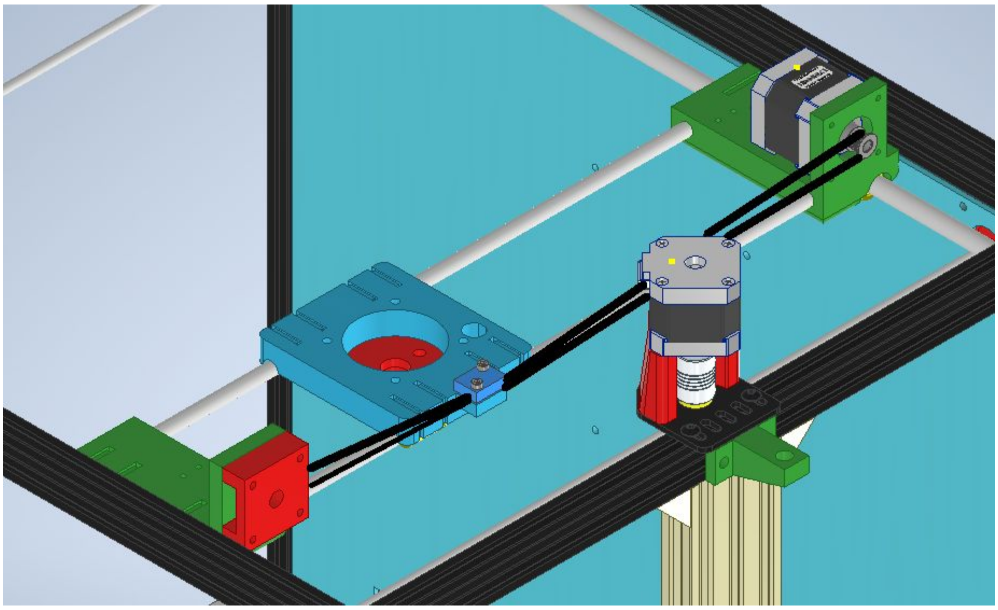

Figure 41. X axis belt.

For this last step is required to place the belts of the X axis and the Y axis as shown in the image. Is highly important to tighten the belts to have good precision in the printer.

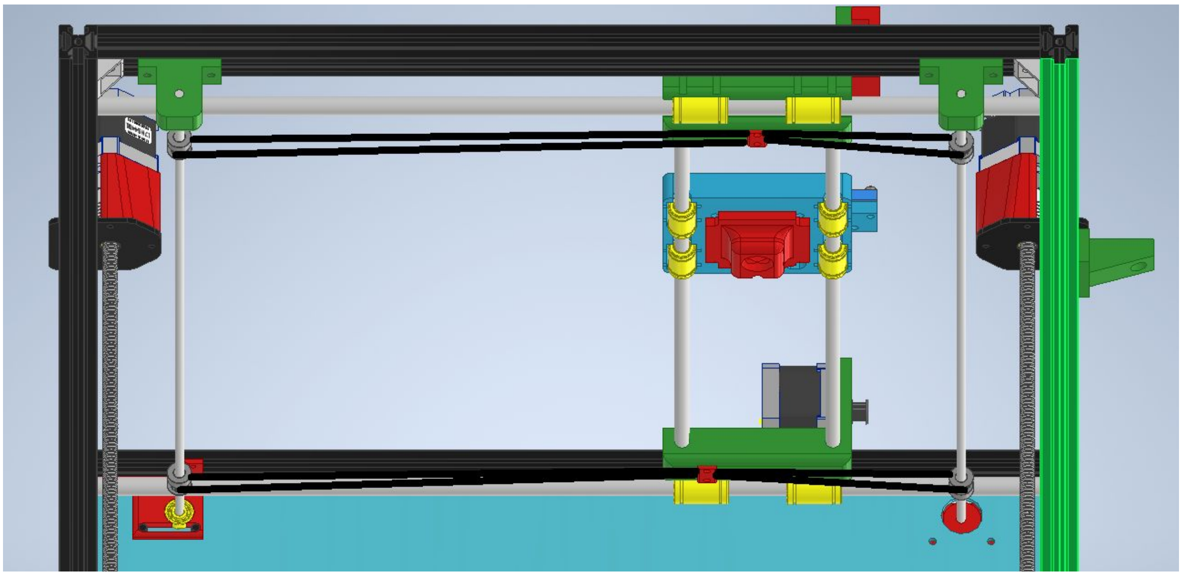

Figure 42. Y axis belt.

Final Step

This will be the final disposition of the structural part of mounting this 3D printer. In the next part the electronic and electric part will be explained. With this and with the final software the 3D printer will be completed for normal use.

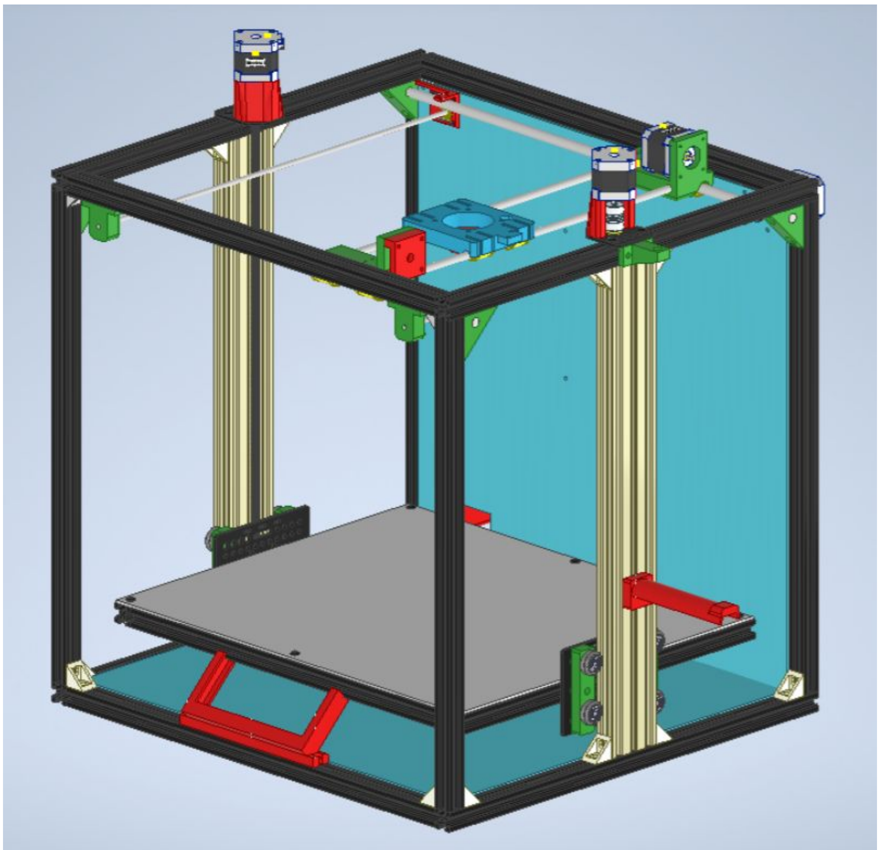

Figure 43. Structural mounting.

6.2 Electric and electronic mounting

In this part of the mounting, the electric and electronic parts of the project will be mounted. This first image should be used as a guide for connecting all the different devices to the controller software. Next, a guide with steps will be followed to mount each one of the pieces.

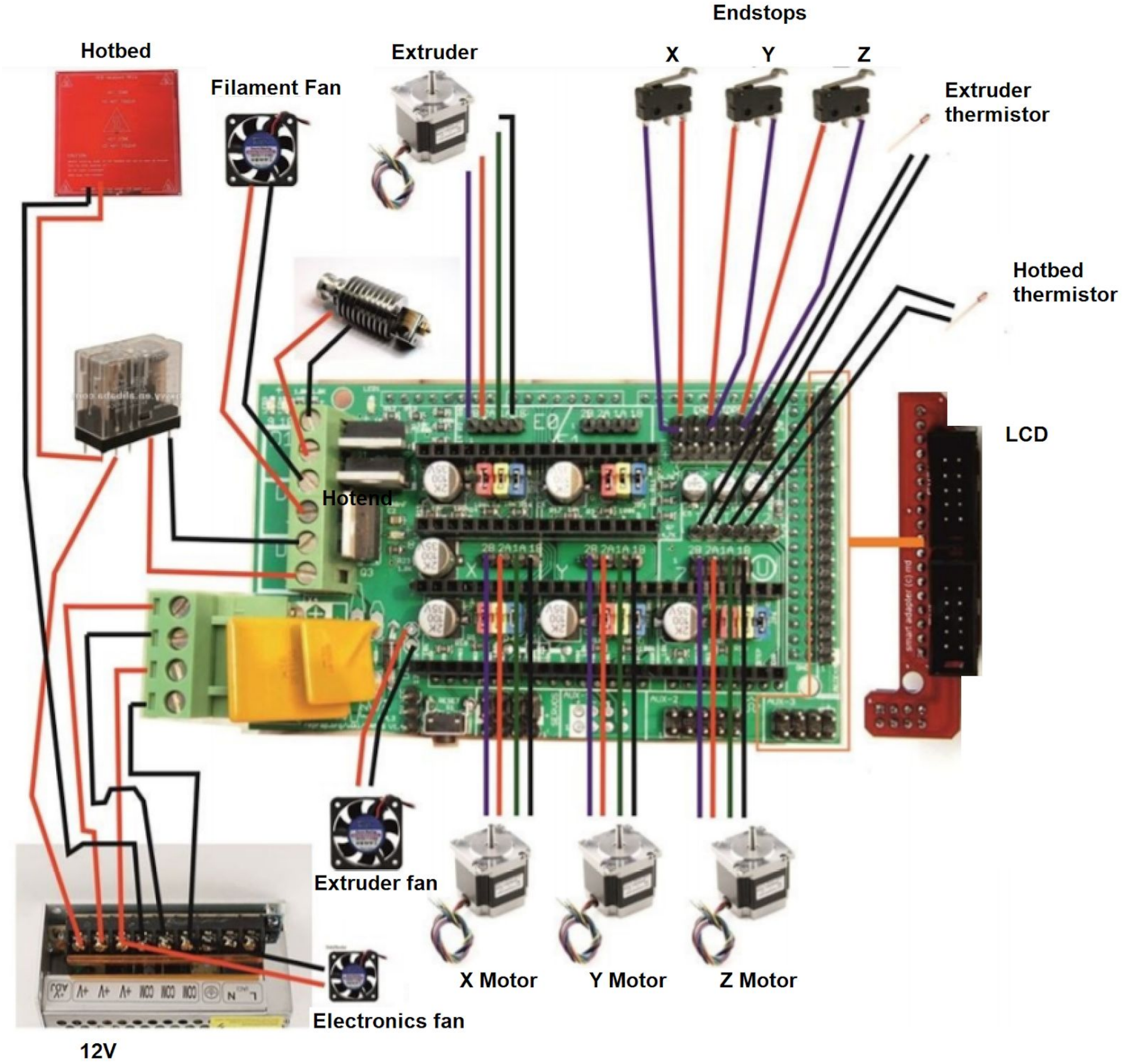

Figure 44. Electronic connections.

1st Step
This first step consists in the mounting of the arduino on the RAMPS base as shown in the image.

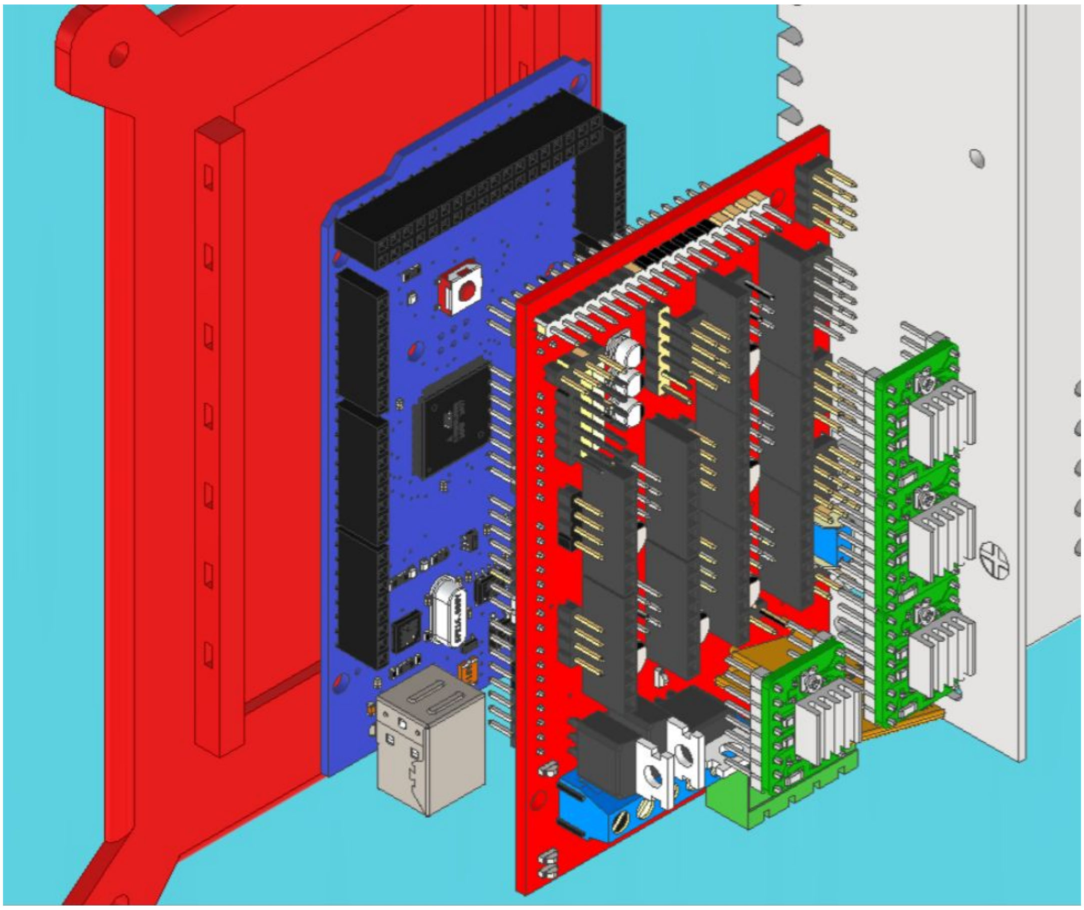

Figure 45. RAMPS Arduino drivers disposal.

2nd Step
The next step is the installation of the drivers A4988, these are the 4 green elements shown in the previous image. It is really important the placement of the jumpers before all of this. 1,8º/16=0,1125º (1,8 of step).

The setup will look like the next picture.

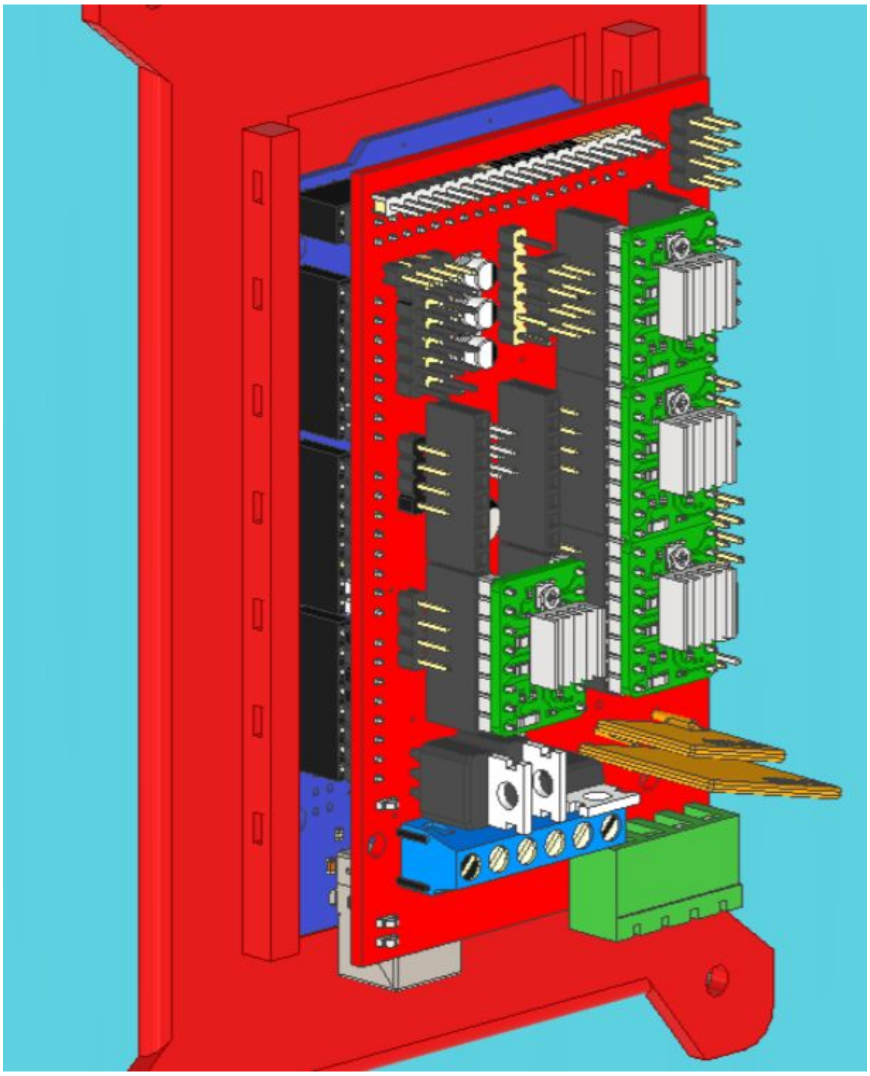

Figure 46. Electronic devices appearance

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3rd Step
In this step the LCD will be installed in its spot in the 3D printer and also connected to the Ramps board as shown in the first image.

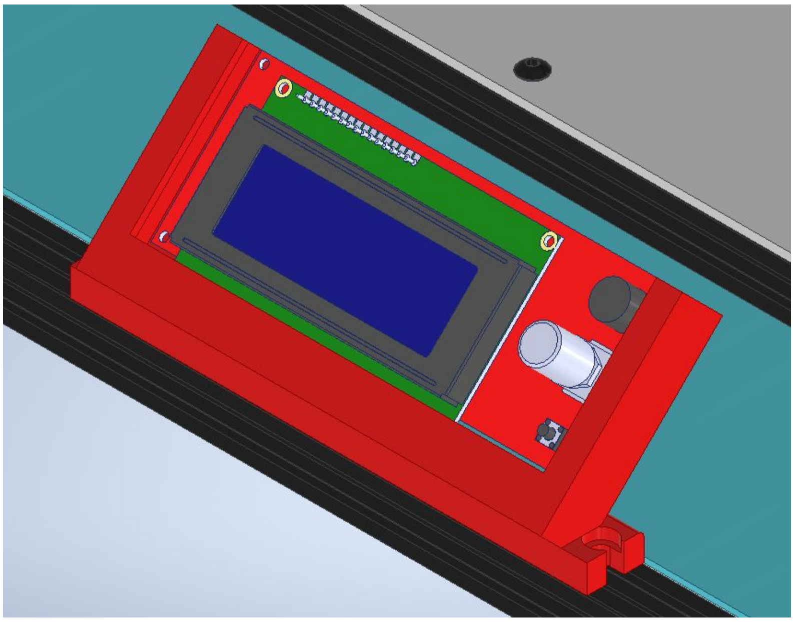


Figure 47. LCD mounting.

4th Step
Each of the motors should be connected in this step, first we will start with the extruder motor and then follow with the X, Y and Z axis. All connected to the RAMPS. Also the BMG extruder.

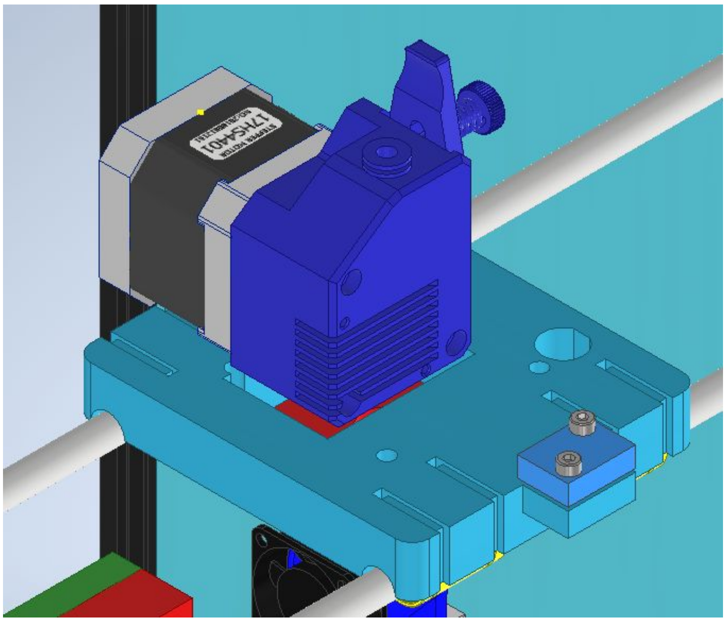


Figure 48. BMG Extruder detail.

5th Step
The temperature sensors will be connected next. The extruder thermistor as well as the hot bed one. Both as shown in the first image.

Figure 49. E3D hotend with installed thermistor.

6th Step
The endstops will be connected in this step. First starting with both Z axis endstops (max and min) and following with both endstops of both X and Y axis. Six end stops in total.

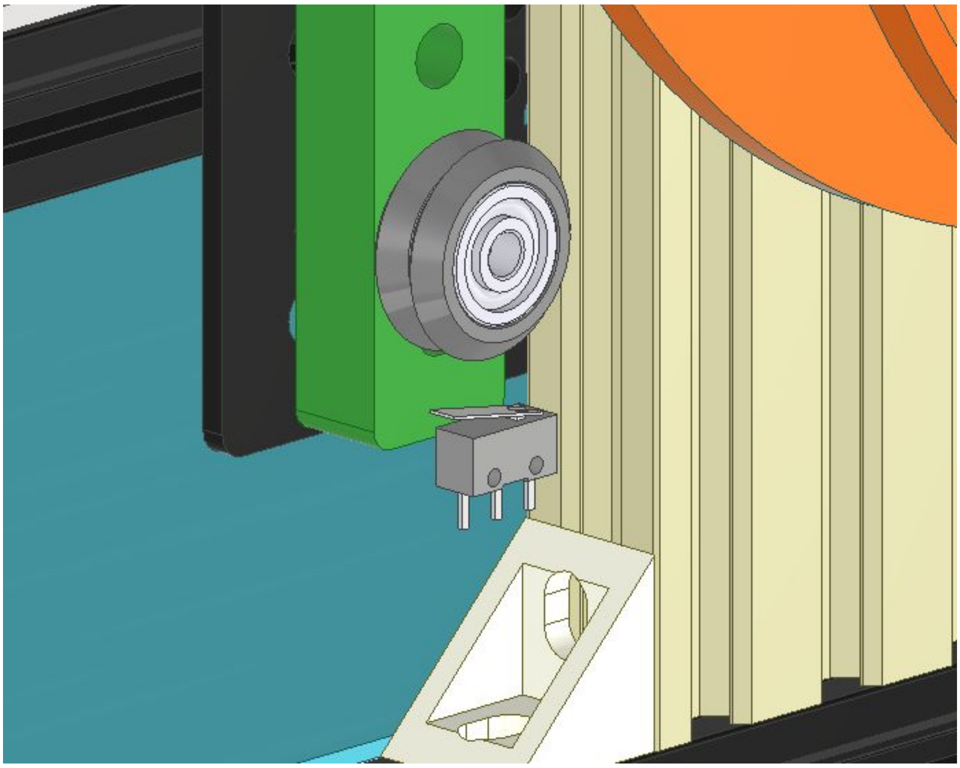


Figure 50. Endstop detail.

7th Step

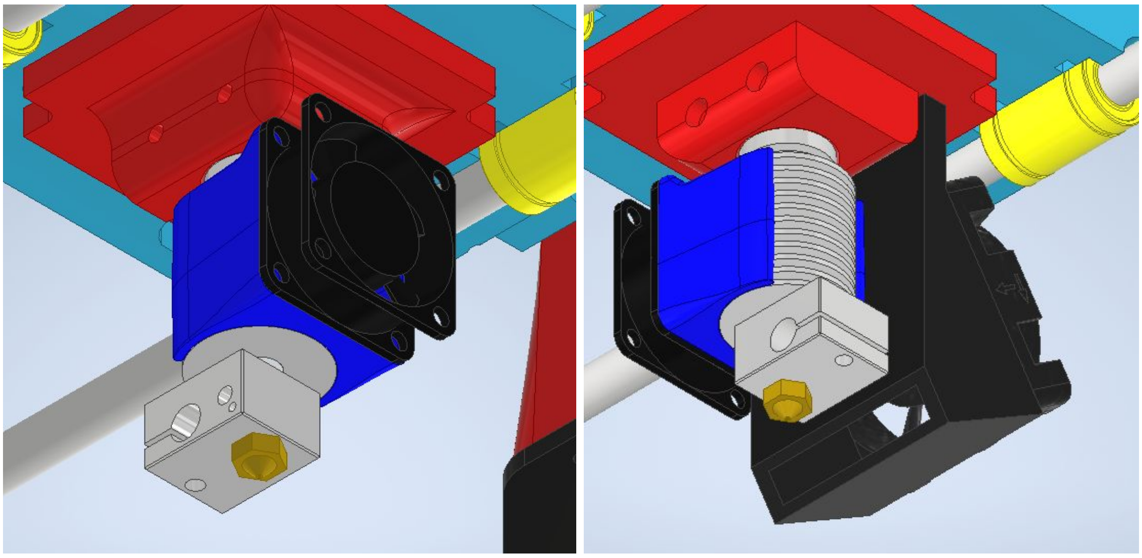


Figure 51. Hotend and filament fan detail.

In this step the hotend will be installed, as well as the fan for the filament and the cables of the hot bed.

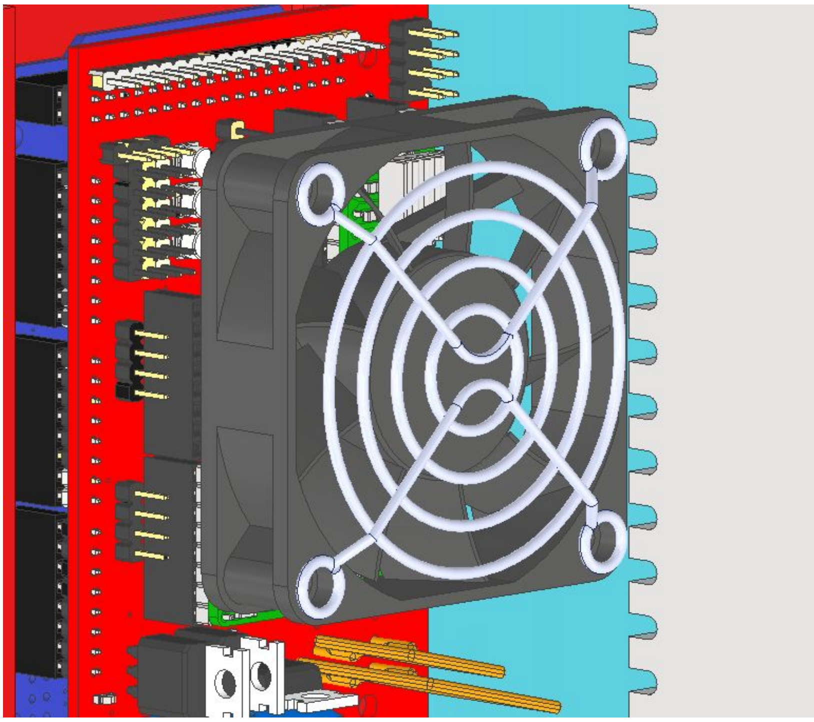


Figure 52. Electronics fan detail.

8th Step

The fan for the 12V electronic will be connected next to the power supply and also the On/Off switch.

6.3 Final adjustment and error

The main objective of this part is calibrating the printer, mainly the motors and the base. It will be separated in two parts, the firmware adjustment and the mechanical adjustment.

The first part consists in adjusting the steps that will be taken by the motors to obtain 1 mm of movement on the X and Y axis. As well as the calculations of maximum velocity and acceleration. Due to the calculation of minimum movement, we will also be able to obtain the printing error of the machine. In the second part the base will be adjusted to prepare the 3D printer for the first printing, calibrating the mechanical parts of the printer.

6.3.1 Firmware adjustment

All these calculations will be prepared only in a theoretical way, but there is no option to check them in a physical 3D printer model.

X and Y Axis: These axis motors are designed with Gt2 pulleys of 20 teeth and 2 mm of step both of them. So the calculations will be the same for both the X and Y axis. The movement is calculated next.

$$\frac{LinearMovement}{Turn} = Teeth\ n^{o} \times\ Step = 20 \times 2mm = 40mm$$

Equation 1. Linear movement by turn calculation.

Next, taking in consideration that the step motors have 200 steps each turn and the drivers are able to divide these steps 16 times, we obtain the next equation for the resolution.

$$X\ and\ Y\ axis\ Resolution = \frac{\left(\frac{LinearMovement}{Turn}\right)}{MotorSteps \times\ DriverMultiplier} = \frac{40mm}{200 \times 16} = 0.0125\ mm$$

Equation 2. X and Y axis resolution.

After this calculation, the number of steps by millimeter is able to calculate following the next equation.

$$Steps\ each\ millimeter = \frac{1}{0,0125} = 80\ Steps$$

Equation 3. X and Y axis steps for a millimeter.

With this calculation the number of steps that one motor should produce to move 1 mm the nozzle is calculated. Both the X axis and the Y axis will have the same number of steps, 80 by millimeter.

Z Axis : The spindle in this case will be the producer of the step. The selected for this printer is Tr8x2.0 so for each turn the movement will be 2 mm. Then as well as before:

$$Z\ axis\ Resolution = \frac{\left(\frac{LinearMovement}{Turn}\right)}{MotorSteps \times DriverMultiplier} = \frac{2\ mm}{200 \times 16} = 0,000625\ mm$$

Equation 4. Z axis resolution.

And with the same equation as before

$$Steps\ each\ millimeter = \frac{1}{0,000625} = 1600\ Steps$$

Equation 4. Z steps for a millimeter

.

Extruder: In this case the value of the steps by millimeter of the extruder is provided by the manufacturer. This value is also called E-Steps and in our BMG extruder is 415 Steps/mm.

6.3.2 Mechanical adjustment

This mechanical adjustment will be separated in 3 different steps.

Greasing guide: It is really important to obtain a correct accuracy and functioning of the machine to grease all the linear guides. With this we obtain a reduccion on the vibrations.

It is also important to center all the guides and bearings to obtain maximum precision and ease for the movement.

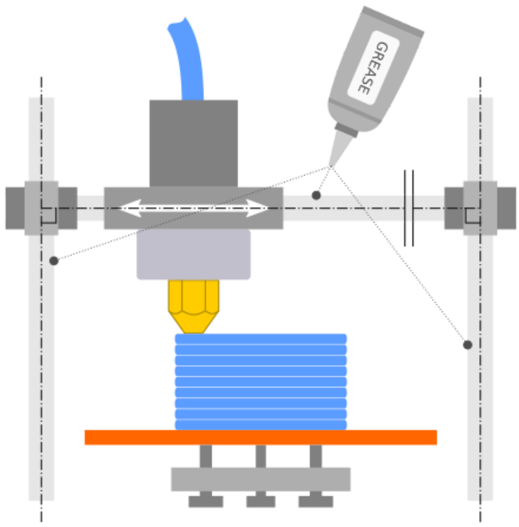


Figure 53. Greasing all the axis.

Belt tightening: In this 3D printing design is highly important a correct tightening of the belts of the X and Y axis. Two people will be required in the mounting of the belts, while one person tightens the belts the second one should screw them to the fixing parts. Without a correct tighten of the belts, the 3D printer will suffer a decay in its accuracy.

Base adjustment: The most important part of the mechanical adjustment is the base calibration. The tip of the hotend has to be placed 0,1 mm on top of the base in every zone of the board.

For this, the springs deployed in each corner of the base have to be calibrated. Repeating the process in each zone until the base is evenly distributed. If this step is not done correctly, the pieces will not adhere to the hotbase and the printing will be impossible.

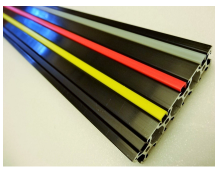
7. List of materials

In the next list, all the needed materials for the correct assembling and mounting of the 3D printer will be exposed. An arbitrary numeration has been adjudged for each of the pieces. the meaning of the numeration is exposed next:

- ST : Buyed structural and mechanical pieces directly from the distributor.
- EL : Buyed electronic and electrical parts from the distributor.
- PP : Printed pieces with the support 3D printer.

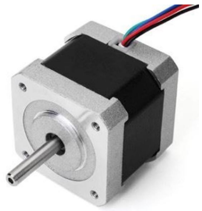
First all the mechanical and structural parts will be presented, next the electronic devices and lastly the designs of the 3D printed pieces.

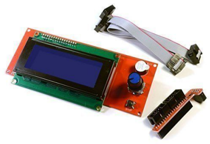
7.1 Structural and Mechanical				
Number	Name	Image	Description	Units
ST001	Z Axis Connection		Aluminum coupling 5-8 mm	2
ST002	Gt2 Pulleys		Gt2 type 20 teeth	6
ST003	Gt2 Belts		Gt2 type 1 meter	3

ST004	Tee Nuts (25 Units)		Box structure	4
ST005	Dual V Wheel Kit		Wheels Pack	8
ST006	8mm Metric Lead Screw		Tr8x2.0 Trapezoidal screw (1 Meter)	1
ST007	Cast - 90º corner		Box structure corners	28
ST008	Threaded Rod Plate		Z axis motor support	2
ST009	V-Slot Gantry Plate		Z axis union to base	2
ST010	Lock Collar		Spindle lockers	2
ST011	Slot cover		Cables covers 500 mm	2
ST012	V-slot 20x20 mm		Standard aluminum profile guides 500mm	16

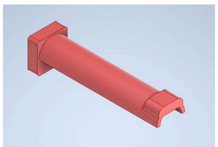
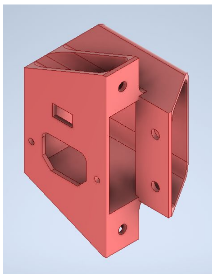
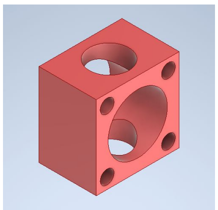
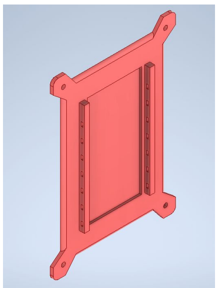
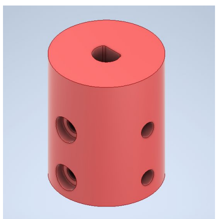
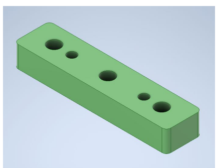
ST013	V-Slot 20x60 mm		Triple profile (1 meter)	1
ST014	688z Ball Bearing 8x16x5		Z Axis Bearings	4
ST015	625Z Ball Bearing 5x16x5		X Axis Bearings	3
ST016	608Z Ball Bearing 8x16x8		Y Axis Bearings	2
ST017	M10 Bearing		LM10UU Bearing	4
ST018	M8 Bearing		LM8UU Bearing	4
ST019	Smooth M10 Rod		X axis (1 Meter)	3
ST020	Smooth M8 Rod		Y Axis (1 Meter)	1
ST021	8mm ACME Nut Block		Z Axis BAse Fixing Block	2

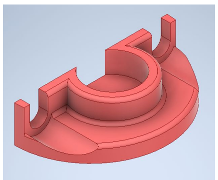
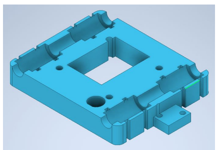
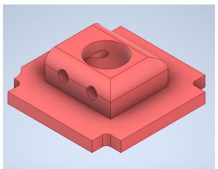
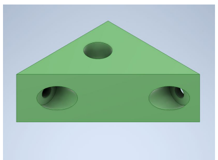
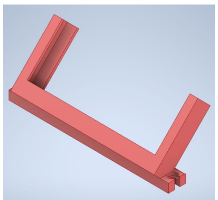
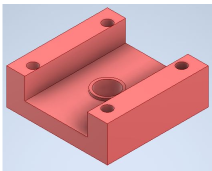
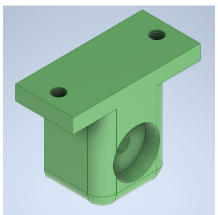
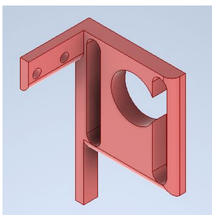
ST022	Aluminum 500x500x3 mm		Box, base and 3D printer Back	3
ST023	PLA coil 1kg		Printed pieces plastic	0.6
ST024	Filament guide		PTFE Guide (1 Meter)	1
ST025	Low profile Screws M5		8mm/25 Units	3
ST026	Low profile Screws M5		10mm/25 Units	1
ST027	Hexagonal Head Screws (Allen)		M5x20 mm	2
ST028			M5x40 mm	8
ST029			M8x30 mm	1
ST030			M3x6 mm	4
ST031			M3x10 mm	12
ST032			M3x20 mm	6
ST033			M3x25 mm	4
ST034			M3x35 mm	4
ST035			M3x45 mm	6
ST036			M4x25 mm	4

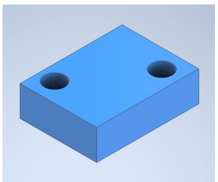
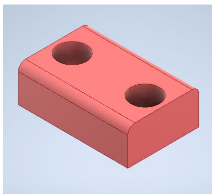
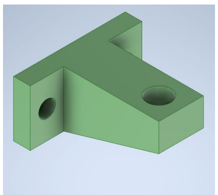
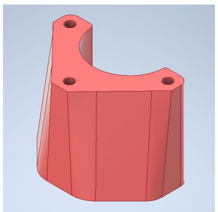
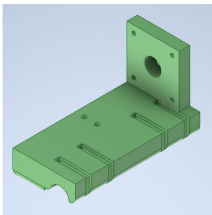
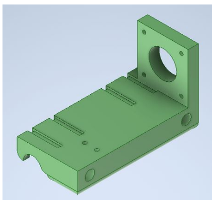
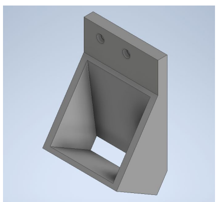
7.2 Electronics				
Number	Name	Image	Description	Units
EL001	Motor Nema 17		SHD404-22	5
EL002	E3D Hotend 1.75 mm		Bowden Type	1
EL003	BMG Extruder All Black		3D Extruder	1
EL004	Pack Hot Bed		-Mk2 Hot Base -Mirror -Thermistor NTC 100k -Calibration Springs	1
EL005	Electronics Kit		-Ramps 1.4 -Arduino Mega 2560 R3 -4x Stepper Driver with sinks	1
EL006	Power supply		12V 30A 360W	1

EL007	LCD Ramps 1.4		Controller LCD -SD controller -Cables and adapter	1
EL008	Switch Snap		2 for each Axis	6
EL009	60x60 Fan		Electronics Fan	1
EL010	40x40 Fan		Extruder and filament Fan	2
EL011	Parallel Cable 1mm²		Red/Black Cable (1m)	2
EL012	Single line 0.28mm² cable		Red (1m)	6
EL013	Single line 0.28mm² cable		Black (1m)	6
EL014	On/off Switch		Power Switch	1
EL015	Power supply connector		General power supply female connector	1

7.3 Printed Parts

Number	Name	Image	Description	Units
PP003	Coil Support		Filament Coil Support to Structure	1
PP004	Power Structure		Structure to fix the ON/OFF switch and the main power cable	1
PP005	Motor spacer		Spacer for X axis motor	1
PP006	Electronics support		Board for printers back electronics	1
PP007	X axis motor connection		X axis connection to motor	1
PP008	VSLOT Spacer		Spacer for Z axis wheels	4

PP009	Spindle end		Base blockage and Spindle end	2
PP010	Extruder support		Y Axis and extruder+hotend support	1
PP011	Extruder union		Extruder and hotend union to Y axis	1
PP012	M10 Corner		Corner for M10 rods	4
PP013	LCD support		Support for fixing LCD to structure	1
PP014	Pulley closer		Closer for Y axis pulley	1
PP015	X axis closer		Support for X axis rods	2
PP016	X axis support		Back support for X axis	1

PP017	Belt block X		Belt block for X axis	1
PP018	Belt block Y		Belt block for T axis	1
PP019	Filament guide		Support for filament guide	1
PP020	Z axis spacer		Spacer for Z axis motors	2
PP021	XY front union		Front union X and Y	1
PP022	XY back union		Back union X and Y with motor	1
PP023	Extruder fan support		Support to focus fan cooling	1

8. Cost analysis

This part is aimed to analyze the costs of manufacture of this 3D printer. All the prices of the different parts of this machine will be exposed to have better knowledge of the approximate price of the 3D printer. The cost of design and manufacture of the 3D printer are also taken into account. All with approximate hours of work and approximate prices each hour.

These parts will be classified into bought materials, standard parts, printed and manufactured parts. After the design and assembly cost will be calculated.
It is important to clarify that all the prices include national taxes as well as shipping and transport costs. All the prices presented in Euros (EUR).

8.1 Structural and Mechanical					
Number	Name	Description	Units	Price by Unit	Price
ST001	Z Axis Connection	Aluminum coupling 5-8 mm	2	0,52 €	1,04 €
ST002	Gt2 Pulleys	Gt2 type 20 teeth	Kit	13,16 €	13,16 €
ST003	Gt2 Belts	Gt2 type 1 meter			
ST004	Tee Nuts (50 Units)	Box structure	2	1,56 €	3,12 €
ST005	Dual V Wheel Kit	Wheels Pack	8	2,54 €	20,32 €
ST006	8mm Metric Lead Screw	Tr8x2.0 Trapezoidal screw (1 Meter)	1	33,99 €	33,99 €
ST007	Cast - 90º corner	Box structure corners	28	0,65 €	18,2 €
ST008	Threaded Rod Plate	Z axis motor support	2	9,68 €	19,36 €
ST009	V-Slot Gantry Plate	Z axis union to base	2	17,16 €	34,32 €
ST010	Lock Collar	Spindle lockers	2	1,49 €	2,98 €
ST011	Slot cover	Cables covers 500 mm	2	2.95 €	5,90 €
ST012	V-slot 20x20 mm	Standard aluminum profile guides 500mm	16	2,19 €	35,04 €

ST013	V-Slot 20x60 mm	Triple profile (1 meter)	1	4,00 €	4,00 €
ST014	688z Ball Bearing 8x16x5	Z Axis Bearings	4	0,47 €	1,88 €
ST015	625Z Ball Bearing 5x16x5	X Axis Bearings	3	1,52 €	4,56 €
ST016	608Z Ball Bearing 8x16x8	Y Axis Bearings	2	0,82 €	1,64 €
ST017	M10 Bearing	LM10UU Bearing	4	0,85 €	3,40 €
ST018	M8 Bearing	LM8UU Bearing	4	1,07 €	4,28 €
ST019	Smooth M10 Rod	X axis (1 Meter)	3	18,99 €	56,97 €
ST020	Smooth M8 Rod	Y Axis (1 Meter)	1	8,90 €	8,90 €
ST021	8mm ACME Nut Block	Z Axis Base Fixing Block	2	1,67 €	3,34 €
ST022	Aluminum 600x1000x3 mm	Box, base and 3D printer Back	2	39,30 €	78,60 €
ST023	PLA coil 1kg	Printed pieces plastic	0.6	21,50 €	12,90 €
ST024	Filament guide	PTFE Guide (1 Meter)	1	2,51 €	2,51 €
ST025	Low profile Screws M5	8mm/10 Units	8	0,65 €	5,20 €
ST026	Low profile Screws M5	10mm/10 Units	3	0,65 €	1,95 €
ST027	Hexagonal Head Screws (Allen)	M5x20 mm	2	0,05 €	0,10 €
ST028		M5x40 mm	8	0,16 €	1,28 €
ST029		M8x30 mm	1	0,18 €	0,18 €
ST030		M3x6 mm	4	0,02 €	0,08 €
ST031		M3x10 mm	12	0,07 €	0,84 €
ST032		M3x20 mm	6	0,08 €	0,48 €
ST033		M3x25 mm	4	0,08 €	0,32 €
ST034		M3x35 mm	4	0,10 €	0,40 €
ST035		M3x45 mm	6	0,10 €	0,60 €
ST036		M4x25 mm	4	0,12 €	0,48 €

Total Structural and Mechanical Costs	382,32 €

8.2 Electronics

Number	Name	Description	Units	Price by Unit	Price
EL001	Motor Nema 17	SHD404-22	5	10,30 €	51,50 €
EL002	E3D Hotend 1.75 mm	Bowden Type	1	62,90 €	62,90 €
EL003	BMG Extruder All Black	3D Extruder	1	15,28 €	15,28 €
EL004	Pack Hot Bed	-Mk2 Hot Base -Mirror -Thermistor NTC 100k -Calibration Springs	1	15,22 €	15,22 €
EL005	Electronics Kit	-Ramps 1.4 -Arduino Mega 2560 R3 -4x Stepper Driver with sinks	1	60,50 €	60,50 €
EL006	Power supply	12V 30A 360W	1	21,22 €	21,22 €
EL007	LCD Ramps 1.4	Controller LCD -SD controller -Cables and adapter	1	13,95 €	13,95 €
EL008	Switch Snap	2 for each Axis	6	0,90 €	5,40 €
EL009	60x60 Fan	Electronics Fan	1	2,77 €	2,77 €
EL010	40x40 Fan	Extruder and filament Fan	2	1,98 €	3,96 €
EL011	Parallel Cable 1mm²	Red/Black Cable (1m)	2	0,09 €	0,18 €
EL012	Single line 0.28mm² cable	Red (1m)	6	0,09 €	0,54 €
EL013	Single line 0.28mm² cable	Black (1m)	6	0,09 €	0,54 €
EL014	On/off Switch	Power Switch	1	1,12 €	1,12 €
EL015	Power supply connector	General power supply female connector	1	0,92 €	0,92 €

Total Electronics and devices Costs	256,00 €

8.3 Design				
Name	Description	Units	Price by Unit	Price
3D printer design and design	Hours dedicated to digital design as well as materials selection	160	25,00 €	4000 €
Design total				4000 €

8.4 Printing and Assembly				
Name	Description	Units	Price by Unit	Price
Pieces Manufacture	Hours dedicated to manufacture all the 3D pieces as well as aluminum walls	8	15,00 €	120,00 €
Assembly	Hours dedicated to assembly of the 3D printer	16	15,00 €	240,00 €
Printing and Assembly total				360,00 €
Total Human Costs				4360 €

8.5 Total	
Total Materials and Human Costs	4998,32 €
General Expenses (13%)	649,78 €
Industrial Benefits (6%)	338,88 €
Total Without Taxes	5986,98 €

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